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Assessment of information used to develop a Recovery Potential assessment for basking shark *Cetorhinus maximus* (Pacific population) in Canada

Évaluation de l'information utilisée pour élaborer une évaluation du potentiel de rétablissement du requin pèlerin, *Cetorhinus maximus* (population du Pacifique), au Canada

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ABSTRACT

Basking sharks (Canadian Pacific population) are now suggested for listing as Endangered under the Species at Risk Act. We assessed recovery potential for basking sharks in Canadian Pacific waters by considering current status, potential sources of human-induced mortality, and various strategies to mitigate harm and promote recovery. We used a simulation model to evaluate scenarios that span the range of plausible human activities that cause mortality. Basking sharks in Canadian Pacific waters are considered to be part of a North American Pacific coast population which migrates into Canadian waters in spring and summer and winters off California. We therefore assess scenarios for the whole Pacific coast.

Best estimates of current abundance range from 321 to 535 individuals. It is estimated that the decline from pre-exploited numbers exceeds 90%. It is believed that the bycatch of basking sharks in commercial fisheries limits current abundance. Other threats to the population (collisions with marine traffic, coastal development, ecotourism, etc) were identified, and mitigation proposals examined.

Specified recovery objectives that could be assessed through simulation modelling include a) rebuild to 1000 breeding pairs; b) attain 30, 40, 50, and 99% of carrying capacity (assumed equal to pre-exploitation numbers), and c) attain 30, 40, 50,and 99% of initial biomass (assumed to be biomass prior to exploitation). Recovery potential was estimated as the number of years required to attain the recovery objectives under four levels of human-induced mortality and evaluated using two plausible catch histories.

Using the best estimates of current abundance and stock decline, production model projections suggest that if a breeding population currently exists in the northeast Pacific Ocean, and no further human-induced mortality and changes to existing habitat occurs, that approximately 200 years are needed before population numbers will return to their unexploited states (Appendix C). If these animals are afforded complete protection, it will still take hundreds of years for the population to recover to 1000 breeding pairs. Recovery to 30% of the original biomass could happen within 45 years, if complete protection is afforded. The fishing mortality that the population can sustain without suffering further decline from the 2007 population ranges from 10 to 17 individuals annually coast wide including Canadian and US waters.

Basking shark is a long lived species with a low rate of increase (i.e., Generation time of 22-33 years). The uncertainties in the projections of this report increases with time. To make progress in rehabilitating the basking shark population, will require government agencies to promote research and management activities for decades.

Resume

Il est maintenant proposé d'inscrire le Requin pèlerin (population canadienne du Pacifique) comme espèce en voie de disparition en vertu de la Loi sur les espèces en péril. Nous avons évalué le potentiel de rétablissement du requin pèlerin dans les eaux canadiennes du Pacifique d'après sa situation actuelle et les éventuelles sources de mortalité d'origine anthropique et en fonction des diverses stratégies d'atténuation des dommages et de promotion du rétablissement. Nous avons utilisé un modèle de simulation pour évaluer des scénarios qui couvrent l'éventail des activités humaines pour lesquelles il est réaliste de penser qu'elles constituent des causes de mortalité. Les requins pèlerins des eaux canadiennes du Pacifique sont considérés comme faisant partie d'une population de la côte du Pacifique de l'Amérique du Nord migrant dans les eaux canadiennes au printemps et à l'été, et hivernant en Californie. Nous évaluons donc des scénarios pour l'ensemble de la côte du Pacifique.

Les meilleures estimations de l'abondance actuelle se situent entre 426 et 659 individus. On estime que le déclin du nombre d'individus pré-exploitation dépasse 90 %. On croit que la prise accessoire de requins pèlerins dans les pêches commerciales limite l'abondance actuelle. D'autres menaces pour la population (collisions avec les navires de trafic maritime, aménagement du littoral, écotourisme, etc.) ont été déterminées et des propositions d'atténuation ont été examinées.

Les objectifs de rétablissement particuliers qui pourraient être évalués grâce aux modèles de simulation comprennent : a) rétablir 1 000 couples reproducteurs; b) atteindre 30, 40, 50 et 99 % de capacité de charge (supposée égale au nombre d'individus pré-exploitation); c) atteindre 30, 40, 50 et 99 % de la biomasse initiale (biomasse supposée avant l'exploitation). Le potentiel de rétablissement a été estimé comme étant le nombre d'années nécessaires pour atteindre les objectifs de rétablissement en fonction de quatre niveaux de mortalité d'origine anthropique et évalué à l'aide de deux historiques plausibles des prises.

En utilisant les meilleures estimations de l'abondance actuelle et le déclin des stocks, les projections du modèle de production laissent entendre que s'il existe à l'heure actuelle une population en âge de reproduction dans le nord-ouest de l'océan Pacifique, qu'aucune mortalité d'origine anthropique ne survient et qu'aucun changement n'est apporté à l'habitat existant, il faudra environ 200 ans pour que la taille de la population revienne à sa situation avant l'exploitation (annexe C). Même en accordant une protection complète à ces animaux, il faudra encore des centaines d'années à une population de 1 000 couples reproducteurs pour se rétablir. Le rétablissement de la biomasse originale à 30 % pourrait prendre 45 ans si une protection complète est accordée. La mortalité par pêche que la population peut soutenir sans souffrir d'un autre déclin par rapport à la population de 2007 varie entre 6 à 10 individus annuellement dans l'ensemble de la côte.

Le requin pèlerin est une espèce à grande longévité ayant un faible taux d'accroissement (c.-à-d. une durée de génération de 22 à 33 ans). Les incertitudes des projections contenues dans ce rapport augmentent avec le temps. Pour accomplir des progrès dans le rétablissement de la population des pèlerins, les organismes gouvernementaux devront faire la promotion des activités de recherche et de gestion pendant des décennies.

INTRODUCTION

This document provides a comprehensive Recovery Potential Assessment (RPA) for a remnant population of basking sharks in the Canadian Pacific that is now suggested for listing as Endangered under the Species At Risk Act (SARA). An RPA is a scientific evaluation of the likelihood that specified recovery goals can be achieved in biologically reasonable time frames. Feasibility of recovery is assessed under various scenarios that span the range of plausible human activities that cause mortality. Background information on the biology and distribution of basking sharks in Canada is presented in Appendix A.

This assessment comprises three phases. In phase 1, we present the current population status of basking sharks and summarize what is known about recent trends in abundance of the population in Canada's Pacific and in contiguous waters of the northeast Pacific (Appendix B). We describe what little is known of the habitat characteristics that may be critical to persistence or recovery of the population. Recovery targets were formulated and applied to a production model which estimates the likelihood that recovery targets will be achieved under the "natural scenario" of no further human intervention, implying no human-induced mortality and no further changes to existing habitat. Details of the simulation modeling are presented in Appendix C.

In phase 2, we compile an inventory of human threats that could jeopardize recovery, considering both human activities that directly threaten individual animals, and other human activities that affect critical habitat and thereby indirectly threaten the viability of the basking shark populations. We present potential catch estimates and simulated population projection scenarios for future recovery to illustrate the likely impact of a range of rates of human-induced mortality.

In phase 3, we present alternatives and modifications to activities that may bring harm or mortality to individuals and have potential to negatively impact critical habitat. The implementation of measures that will improve our understanding of basking shark abundance and decline is discussed, and gaps in our knowledge that hinder scientific evaluation are listed. The likelihood for recovery of the population after implementation of these measures to mitigate harmful impacts is unknown.

PHASE 1: CURRENT STATUS

1. Population status

The Pacific population of basking sharks has been designated as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2007). The abundance history meets the following criteria for this designation:

A population size reduction of >50% has been observed over the past three generations, where the reduction or its causes may not have ceased, may not be understood, or may not be reversible;

The total population size is small, with <2,500 mature individuals, and there is an estimated continuing rate of decline of at least 20% in two generations (44-66 years);

The population is suspected to be very small, at well under 250 mature individuals, with only 6 confirmed sightings of basking sharks since 1996, of which 4 were encountered as bycatch and likely died.

The Pacific population was also designated as Endangered by the IUCN (Fowler 2000 in IUCN 2007), while under the Convention on International Trade in Endangered Species (CITES 2002): Appendix II, basking shark are listed as Vulnerable Globally, and Endangered in the NE Atlantic and North Pacific.

2. Abundance and past trends

It is important to note that basking sharks have only been enumerated while visible at the surface. However, the percentage of time spent at the surface is unknown and is likely influenced by prey distribution, weather conditions, and reproductive behaviours. Basking sharks have been shown to spend more time at the surface in shallow, inner continental shelf areas than in deep, well stratified waters. This is thought to be due to associated differences in migratory behaviour of zooplankton prey; therefore, abundance estimates based on daytime surface sightings may under or overestimate shark abundance by at least 10-fold (Sims *et al.* 2005). Furthermore, those making the sightings are also influenced by weather and sea conditions, and this may bias the interpretation of seasonality of abundance. For example, more surveys are successfully carried out in Monterey Bay, California in October because the weather in October is often calmer and visibility optimal compared to September and November (Forney pers. comm. 2007).

Any decline in abundance of basking sharks has been obscured by historical unpredictability in the occurrence and numbers of basking sharks visiting the coastal areas in which they are seen. Early accounts from central California mention basking sharks returning every twenty years or so, and the sudden appearance of large numbers inspired the establishment of fisheries in the early 1920s and again in the late 1940s (Appendix B). Studies of fluctuating abundance of basking sharks off Ireland indicate that migration patterns may be linked to seasonal and interannual shifts in zooplankton distribution, which are in turn influenced by climate conditions (Sims and Quayle 1998; Sims and Reid 2002). Whether the inconsistent abundances exhibited by basking sharks visiting the northwest coast of North America are related to climate driven changes in sea surface temperature as is suspected for basking sharks off southwest Britain, is unknown (Cotton *et al.* 2005).

Historic trends – abundance and mortality

Estimation of past abundance was made possible by examination of a variety of historical records including scientific sources, newspapers, government records pertaining to the 1945-1970 eradication program, commercial harvest, and sport fishing (COSEWIC 2007; Wallace and Gisborne 2006). Detailed information on historic abundance and fisheries for basking sharks in British Columbia are presented in Appendix B. The conclusions of the COSEWIC (2007) report do not depend on the specifics of the anecdotal and newspaper reports, but these accounts are expected to provide a reliable indication of general abundance and distribution.

From 1900 to 1970, basking sharks were regularly found in numerous locations along British Columbia's coast. Over the time period of three generations (66-99 years), basking sharks have all but disappeared from all areas where they were historically

abundant. The range in generation times of 22 to 33 years comes from 22 years (UK proposal to CITES, 2002); the rate of natural mortality (M) of 0.068 (Pauly 2002) for the report to COSEWIC (2007) and the 33 years that was calculated from an age of female maturity of 18 years (Compagno 1984). Throughout this period (1900 – 1970), basking sharks were subject to a commercial harvest, a directed eradication program, incidental catch, and sport harpooning. It has been estimated that the total number of sharks killed in Canadian waters (1945-1970) by eradication is 413, other patrol/eradication methods (200-300), entanglement (400-1500), and sport kills (50-400) (COSEWIC 2007). This results in a range of kills between 1000-2600.

A minimum historical population of 750 individuals in Canadian Pacific coast waters can be reconstructed from the estimated annual removals from 1945 to1970 (40 individuals, i.e., 1000/25 years) coupled with the estimate of annual productivity (r=0.023) (COSEWIC 2007; Smith *et al.* 1998). In other words, at a mortality rate of 40 animals per year, it would take 25 years for an initial population of 750 to be diminished to zero assuming r=0.023. Note that there is no reliable information on trends in abundance to corroborate this inference.

Current abundance

The current abundance of basking sharks in Canada's Pacific waters is unknown, but all evidence indicates it is much reduced. Evidence from historical records shows a wide distribution with several areas supporting localized aggregations numbering in the hundreds or possibly thousands (Wallace and Gisborne 2006). At present, basking sharks appear infrequently in Pacific waters, with only six confirmed sightings since 1996*, and only ten since 1973 (not including Clayoquot Sound), of which four are from trawl observer records and were likely killed (COSEWIC 2007). Thus, there is no reliable way to estimate the current population size.

Although no comprehensive research survey data exist for basking sharks in Canada's Pacific region, extensive boat-based research surveys of marine mammals have been conducted in coastal habitat suitable for basking sharks for more than 20 years. Since 2002, the coastal surveys were augmented by offshore surveys along the west coast of Vancouver Island, west and east coasts of the Queen Charlotte Islands, and central coast of the mainland (COSEWIC 2007). In addition, surveillance flights (eight with a marine mammal observer) were conducted mostly in 2002 and 2003, covering all parts of the coast to 200 nautical miles offshore (COSEWIC 2007). No basking sharks have been observed in any of these surveys.

A water taxi service, the Juan de Fuca Express, operates along the southwest coast of Vancouver Island between Port Renfrew and Bamfield. Since 1996, at least 1900 passes have been made through these waters during summer months with no records of basking sharks (COSEWIC 2007). The water taxi service is operated by a trained marine mammal observer.

The main historical areas of large aggregations of basking sharks are, Barkley Sound, Clayoquot Sound, and Rivers Inlet. In British Columbia there is an extensive marine tourism industry that overlaps with these historic areas of basking shark

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* Since the time of writing we have had two confirmed sightings reported to us in 2008, and an additional four probable sightings in the 2000-2007 period.

occupancy. If surface-active basking sharks were currently using these areas they would certainly be noticed and reported due the presence of tourism operators, a biological station, fishing operations, and extensive marine transport networks. Investigations in preparation for the report to COSEWIC included an informal telephone and email survey of marine operators (including ferry, transport, and tourism operators), researchers, and educators. From these correspondences there were only six recorded sightings since 1973 (not including Clayoquot Sound which is addressed below) (COSEWIC 2007).

Darling and Keogh's (1994) paper provides a comprehensive list of reliable sightings in Clayoquot Sound and includes 97 sightings in 1992 (27 individual sharks that were identified), 54 basking shark observations from a commercial pilot's flight log (1973-1992, observations in all but 5 years), and six other observations (1988-1991). All observations were from channels and inlets. However, since 1994 there have been no confirmed sightings from Clayoquot Sound (COSEWIC 2007).

Since 1996, the groundfish bottom trawl fishery (outside waters-'Option A') has been monitored intensively (100% at sea observer coverage on all trips). The number of separate bottom trawl tows has averaged about 18,000 per year, yet the database (*PacHarvTrawl*, maintained at the Pacific Biological Station of Fisheries and Oceans Canada, Nanaimo, BC) includes only four reliable records of encounters with basking sharks. There are no known basking shark records in other fisheries surveys, surveillance flights, or catch databases. If basking sharks were present, they would be caught as bycatch in the commercial Pacific hake fishery because both species typically prefer zooplankton-rich waters, yet again, no encounters have been recorded from this fishery, despite 100% at sea observer coverage.

Northeast Pacific abundance trends.

In addition to Barkley Sound, Clayoquot Sound, and Rivers Inlet in British Columbia, the only other areas known for basking shark aggregations in the northeast Pacific Ocean are central and southern California. Historic areas of reported abundance in the northeast Pacific Ocean are shown in Figure 1 and recent (1990 to 2007) areas of reported captures and sightings are shown in Figure 2 (refer to abundance tables in Appendix B).

Basking sharks in British Columbia and California may belong to a single seasonally migrating population. This is based on convincing data showing that the seasonal disappearance of basking sharks from California waters between May and July (Squire 1967, 1990) coincides with the appearance of basking sharks in relative abundance in British Columbia waters (Darling and Keogh 1994). Further evidence for this relationship is found in the coincidental disappearance after 1993 of the small congregations of basking sharks that were seen only in Clayoquot Sound in British Columbia and in Monterey Bay in California in the early 1990s (Appendix B; COSEWIC 2007).

The likelihood that the basking sharks frequenting coastal inlets of British Columbia in summer are the same population of animals occupying central California in the fall and winter underlies the importance of considering all of the basking sharks occurring along the coast of North America as a single population, and one that possibly extends its range offshore into the northeast Pacific Ocean. Recent satellite tracking studies of basking sharks in the Atlantic Ocean have demonstrated that basking sharks

migrate many thousands of kilometres, and incidental catches over deep ocean waters are evidence that they are not confined to occupying the continental shelves of the world's ocean basins (Bonfil 1994; Francis and Duffy 2002; Skomal 2005; Southall *et al.* 2005).

No direct effort has been made to enumerate basking sharks anywhere in the northeast Pacific Ocean since the late 1940s when aerial fish spotters were employed for several years in the basking shark fishery of central California. The following description of trends in abundance uses the shark counts per survey flight made during 1948-1950 as a base upon which to compare other records of shark numbers, both subsequent and previous to the surveys conducted in 1948-1950. Other records of the numbers of sharks consist of those recorded by fisheries observers or on landing slips as bycatch or discards in other fisheries, and those sighted during surveys for marine mammals and other pelagic species.

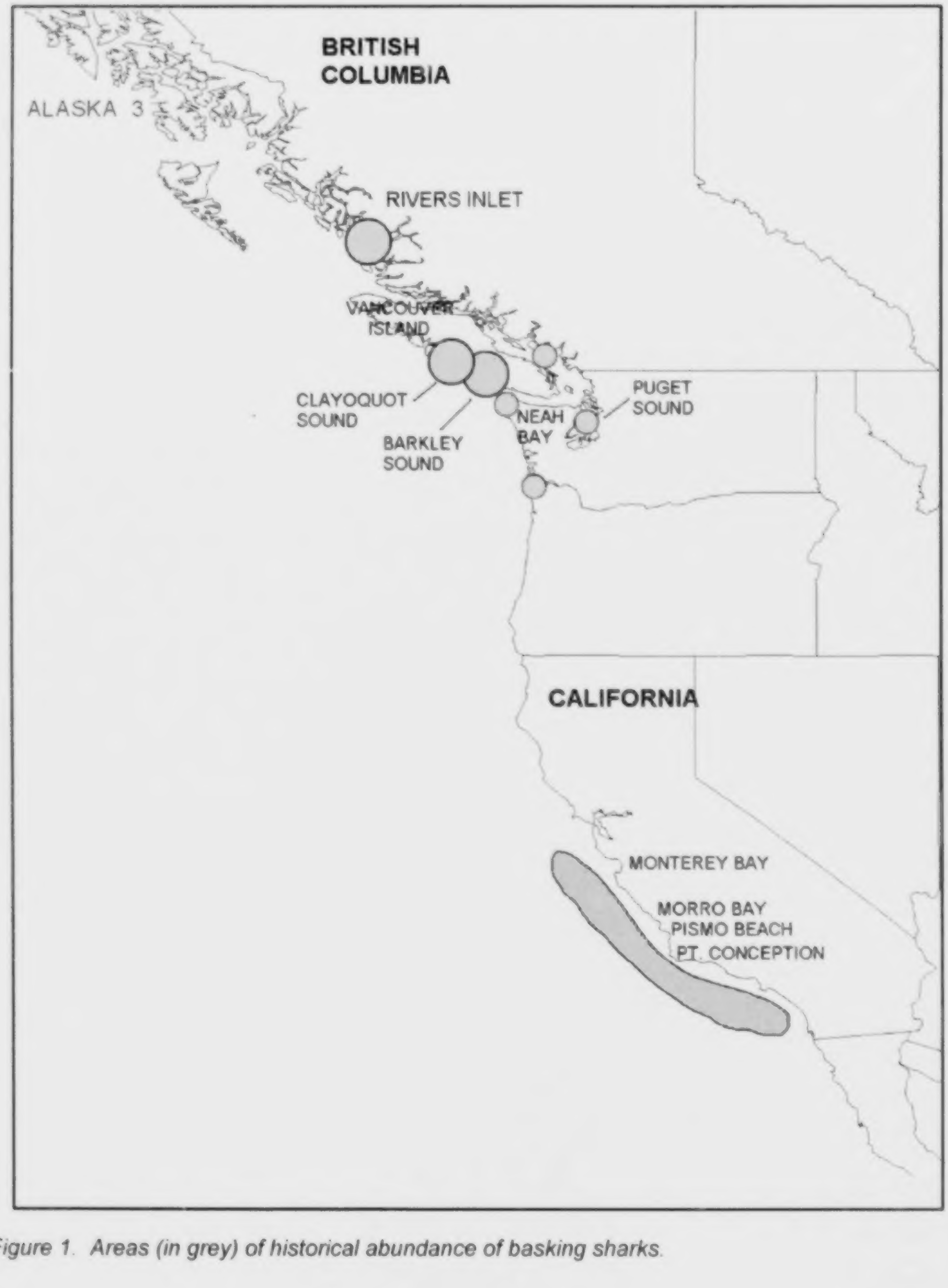

Figure 1. Areas (in grey) of historical abundance of basking sharks.

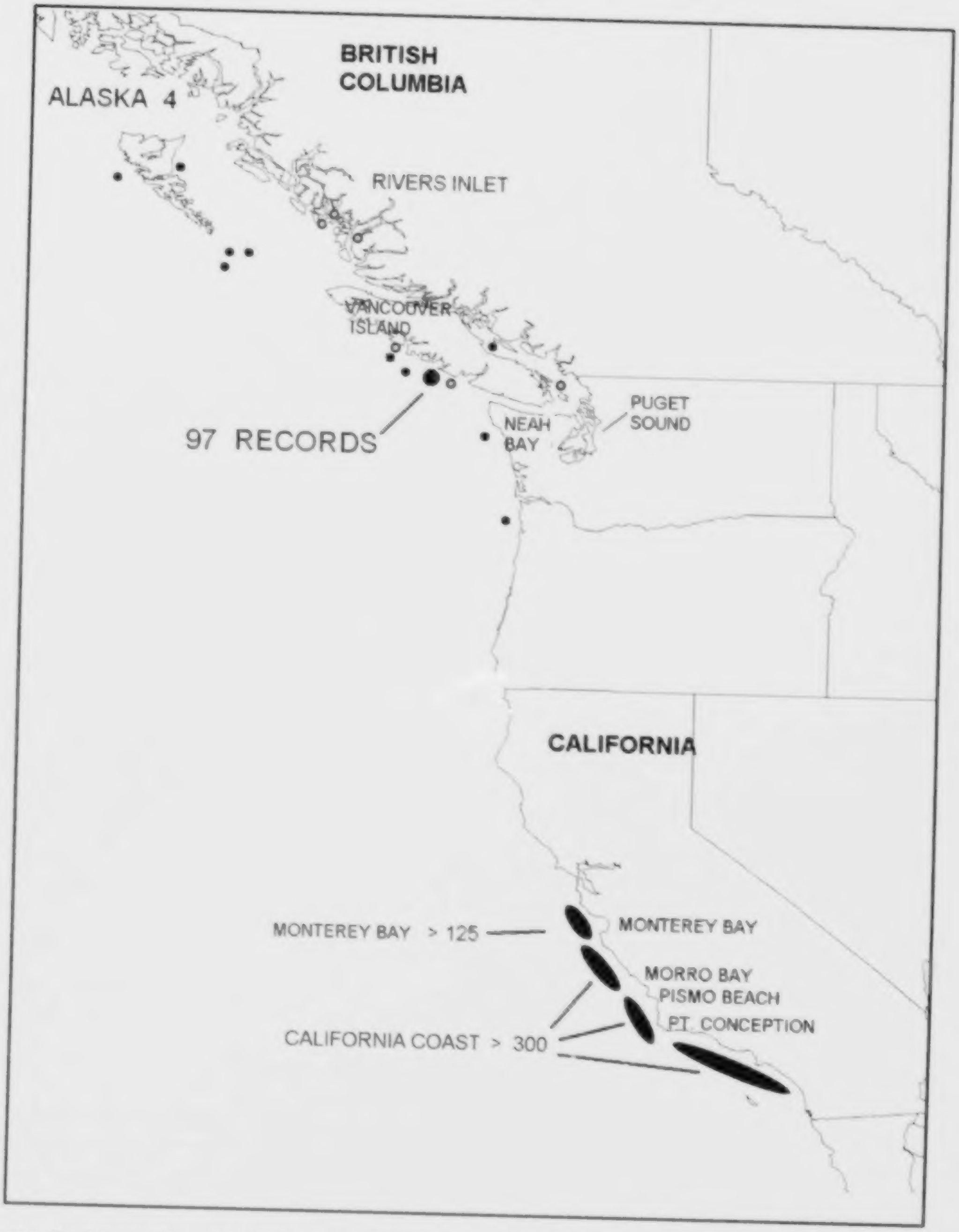

Figure 2. Areas of recent (1990 – 2007) captures and sightings of basking sharks. Individual records (bycatch or confirmed sightings) since 1990 in British Columbia are represented as a single dot except for 97 records indicated off central Vancouver Island (in 1992). Grey circles indicate sightings reported in 2008 since preparation of this report.

Directed fisheries for basking sharks operated from about 1924 to 1938 and from 1946 to 1952 around the Monterey Bay and San Luis Opisbo Bay/Morro Bay areas of California. Information from the directed fisheries provides both a minimum historical abundance for basking sharks in central California, as well as illustrating the decline in abundance over the duration of the fisheries. Detailed information on the history of basking shark fisheries in US coastal waters is presented in Appendix B. One day in October 1948, more than 2000 basking sharks were counted in the Monterey Bay area of California by an a rial fish spotter employed to facilitate the activities of the basking shark fishery (Squire 1967). This sighting has made 2000 the estimated minimum population size of basking sharks in central California at that time. From 100 to 500 sharks were observed on a total of ten different occasions by aerial spotters in Monterey Bay between March 1948 and February 1950. Some 300 basking sharks were landed in the first year of the fishery (1946-1947) that moved between Pismo Beach/Morro Bay and Monterey Bay (Phillips 1948; Roedel and Ripley 1950). It has been estimated that 200 basking sharks were taken in each year from 1948 to 1950, and that effort declined drastically after the spring of 1950 partly due to diminishing numbers of basking sharks (CITES 2002), with the fishery ending by 1952 (Thomas 2004). Prior to this, anecdotal accounts from the 1920s report schools of sometimes hundreds of basking sharks visiting Monterey Bay (Thomas 2004), and aggregations of up to 500 sharks were mentioned by Chute's description in 1930 (Squire 1967) of the new basking shark fishery.

More recently, analysis of basking sharks sightings recorded by a fish spotter employed in an aerial surveying program of the National Marine Fisheries Service (NMFS) and the Southwest Fisheries Science Center (SWFSC) to monitor coastal pelagic fish species for the purse seine fisheries year round off the coast California from 1962 to 1985, revealed a decline in the frequency of sightings and the number of sharks per sighting after 1967 (Squire 1990). During 1962 to 1964, from 50 to 60 sharks were seen per block area flight (i.e. 10 minutes longitude x 10 minutes latitude or 8 x 10 nautical miles at the latitude of California) in blocks where they were observed, and in 1966 almost 140 sharks were seen per block area flight. After 1967 the number of basking sharks seen per block area flight was never more than 10 except in 1981 when 30 basking sharks were seen per block area flight. The greatest abundance of basking sharks were observed in the block area that encompasses Morro Bay, where an average of 98.8 basking sharks per flight were observed on 66 flights on which they were observed, whereas basking sharks were seen less frequently in Monterey Bay where an average of 42 basking sharks per flight were seen on 19 flights. Although basking sharks were never seen in great numbers south of Point Conception, 2 to 3 sharks were observed on 64 occasions in a block area off the coast of Santa Barbara.

The most reliable and consistent enumeration of basking sharks in recent years has been contributed from porpoise and leatherback turtle surveys conducted since 1991 along the coast of California, usually during September through November (Benson *et al.* 2007, Carretta and Forney 2004). Despite surveying thousands of kilometres of traditional basking shark territory in the Morro and Monterey Bay areas during some of the months that basking sharks were historically seen in abundance, only 11 basking sharks have been observed on 5 separate occasions (Appendix B). No basking shark sighting have been made since 2004, and the 4 animals seen in Morro Bay in 2002 and 2003 were observed in September in association with a high abundance of krill that has also not been seen since 2004 (Forney, pers. comm. 2007).

Tagging of basking sharks in the coastal waters of California may indicate that a decline in abundance of basking sharks has occurred since the early 1990s when conventional tags were attached to approximately 146 basking sharks (Refer to Appendix B for details). A total of 81 basking sharks were tagged and released in the Monterey Bay area by the Pelagic Shark Research Foundation since 1990, and of these, 78 were tagged in 1990 and 1991 (Van Sommeran pers. comm. 2007). A total of 58 basking sharks were tagged and released from Monterey Bay to Cabo San Lucas by the California Department of Fish and Game Cooperative Shark Tagging Program; most sharks were tagged in 1991, with a few also tagged in 1990, 1993, and in a follow up program in 2000 (Martarano pers. comm. 2007; Ugoretz 1999). A total of seven basking sharks were tagged and released in the Billfish Tagging Program operated by the Southwest Fisheries Science Center, NOAA Fisheries Service in 1991 (Rasmussen pers. comm. 2007; SWFSC 2006). None of the tagged basking sharks have been recaptured. However, this is not necessarily indicative of a population decline, since although the sharks are easy to tag when they are found slowly feeding at the surface, they are rarely caught incidentally, no directed fishery exists, and since 2000 there has been a prohibition on capture in California (Kohler and Turner 2001).

The unpredictability of basking shark visits to Monterey Bay was noted as early as 1887 in a report by the Monterey Whaling Company that noted that despite the fact that several were in Monterey Bay that year they were considered rare and were sometimes not seen for twenty years (Jordan 1887). Even the basking shark fishery of 1946 to 1952 was said to have begun with the reappearance of basking sharks to Monterey Bay after their absence for several years (Thomas 2004). These historical absences of basking sharks interfere with the recognition of a population decline, whether it be of anthropogenic causes or otherwise.

Genetic considerations

Many sharks have low genetic diversity but basking sharks have the lowest so far determined, and this implies a vulnerability to future environmental changes. Comparison of a mitochondrial DNA control region among basking shark samples from the western North Atlantic, eastern North Atlantic, Mediterranean Sea, Indian Ocean and western Pacific revealed a comparatively low genetic diversity and such little differentiation between ocean basins that it is not possible to designate distinct populations (Hoelzel *et al.* 2006). Such low genetic diversity suggests that the species has gone through some type of population bottleneck event that is further indicated by an estimated effective population size (N_e=8600) that is low for a globally distributed species (Hoelzel *et al.* 2006).

3. Critical habitat

No specific locations have been identified for reproduction, pupping or rearing, although some other shark species are known to mate in northern areas and pup in southern areas. Feeding has been associated with oceanographic fronts which vary both temporally and spatially. There are historical areas that were regularly visited by large numbers of basking sharks (e.g. Barkley Sound, Clayoquot Sound, and Rivers Inlet); however, a recovered stock may not return to these areas. Characteristics that might attract particular life stages such as high seasonal food availability or the occurrence of particular behaviours that might indicate reproductive behaviour have not

been identified in these areas. It is therefore not possible to define critical habitat at this time.

Habitat requirements

The habitat requirements for basking sharks in Pacific Canadian waters have not been investigated. The bays and inlets of reported historical abundance are close to highly productive areas such as La Perouse Bank and Goose Island Gully but the reasons for this association are unknown. Most reports of basking shark sightings come from interactions with human activities, particularly fisheries, and nothing is known of more remote areas. In other areas of the world, basking sharks are known to be associated with oceanographic events that concentrate zooplankton, including fronts off headlands, around islands and in bays with strong fluctuation of water masses from tidal flow (Sims *et al.* 1997; Sims and Quayle 1998; Wilson 2004). While zooplankton abundance has been found to determine distribution of basking sharks at local scales (0.01 to 10 km) (Sims and Quayle 1998), it is sea surface temperatures related to thermal boundary characteristics of tidal and shelf break fronts that are significantly correlated with basking shark distribution and movement patterns over larger scales (10 to 1000 km) (Sims *et al.* 2003 a&b). Thus, long-term distribution patterns may be more related to finding optimal thermal habitat in which metabolic costs are balanced with net energy gains, than to prey abundance alone (Cotton *et al.* 2005). Basking sharks have been recorded in surface waters ranging from 8 to 24°C, with most observations from 8 to 14°C (Compagno 2001). Four sharks tagged with temperature data loggers in the northeast Atlantic were typically found in waters between 9 and 16°C (Sims *et al.* 2003b). The importance of this thermal aspect to habitat and its implications for distribution of basking sharks in a world undergoing climate change should not be underestimated.

Basking sharks have been found to actively seek out areas of high zooplankton concentrations (Sims *et al.* 1997; Sims and Quayle 1998). Several of the rare recent sightings of basking sharks in Monterey Bay occurred in September of 2002 and 2003 when one or two basking sharks was observed feeding in a dense mass of krill, with blue and humpback whales on one occasion (Forney pers. comm. 2007). Sims (1999) calculated that a minimum prey density of between 0.55 and 0.74 $g \cdot m^{-3}$ would be required for net energy gain and corroborated his estimate with field observations. This implies that basking sharks can survive and grow in conditions where prey concentrations are lower than previously thought necessary (Parker and Boesman 1954).

Although they appear to prefer shallow coastal waters, basking sharks have been recorded in the epipelagic zone by aerial surveys, pelagic driftnet fisheries, and have been caught in bottom trawls off the St. Lawrence River, the Scotian Shelf, Scotland and New Zealand (Compagno 2001; COSEWIC 2007; Francis and Duffy 2002). In the northeast Atlantic sharks are generally tracked on or near the edge of the continental shelf in waters less than 200 m deep (Southall *et al.* 2005) while most sharks observed on New Zealand trawlers were near or beyond the edge of the continental shelf (Francis and Duffy 2002). Data from the Newfoundland Observer Program (NOP) indicate that basking sharks have been taken in trawl nets fishing in depths up to 1370 m with 15% of the records (n=414) from waters deeper than 1000 m. Unfortunately, it is difficult to be confident of catch depth in trawl nets since the nets can fish on the way down or on the way up. The deepest catches of sharks in the commercial trawl fishery in New Zealand occurred off the west coast at 700 to 800 m depths during the winter (Jun-Aug), whereas

catches in the other two regions where basking sharks were caught were typically in shallower water, 150 to 400m during spring/summer (Francis and Duffy 2002). Sub-surface diving behaviour is known from only seven animals attached with 'pop-up' archival satellite transmitting tags (PAT tags) which dived to depths well over 200 m and on one occasion to a depth of over 750 m (Sims *et al.* 2003a; Skomal *et al.* 2004; Skomal 2005). In a recent study (Gore et al. 2008), evidence is presented that basking sharks make use of deep-water habitats beyond the shelf edge, with dives of over 1250 m on numerous occasions.

Water column utilization varied considerably among individuals and is likely influenced by patterns of prey distribution varying by depth, location, and season. Skomal (2005) found that two basking sharks captured at the water surface, tagged with PAT tags and released in the same northwest Atlantic summer location moved to very different wintering habitats. One individual wintered off Florida and spent most of its time at the surface, whereas the other individual wintered off of Jamaica and spent most of its time at depths below 480 m. With so few animals tagged it is difficult to characterize diving and water column utilization patterns, except to note that all sharks showed considerable vertical movement.

The influence of ocean habitat type on vertical habitat selection by basking sharks may be driven by diel vertical migration pattern of zooplankton. Sims *et al.* (2005) found that when sharks tagged with satellite tracking tags were occupying deep, well stratified waters they exhibited the normal diel vertical migrations, dusk ascent - dawn descent, of the zooplankton that comprised a migrating sound-scattering layer. However, when they and their zooplankton prey were in shallow, continental shelf areas near thermal fronts, they exhibited reverse diel vertical migrations, dusk descent - dawn ascent, which brought them to the surface and available for daytime sighting. This behaviour has implications for the accuracy of abundance estimates based on surveys that enumerate basking sharks while they are visible at the surface.

Basking sharks periodically shed their gill rakers and are presently thought to cease feeding while they regenerate new ones (in 4-5 months) (Compagno 2001). Their massive livers may act as a metabolic store that maintains energetic requirements while not feeding (Compagno 2001). Recent tagging has largely disproved the longstanding theory that basking sharks 'hibernate' in deep water over the winter (Sims *et al.* 2003b). In New Zealand, high catch rates in the commercial trawl fishery off the west coast occurred in winter in deep water, supporting the idea that basking sharks overwinter in the deep water of the continental slope, but many of the sharks were caught in midwater trawls and so presumed to be active (Francis and Duffy 2002). Peak abundances of basking sharks off the coast of California were observed in fall and winter, and despite the fact that this is not the peak season for plankton abundance, these animals are observed when they are at the surface feeding (Squire 1990).

Marine areas of the Atlantic United States have been designated as Essential Fish Habitat for basking sharks under requirements laid down in fisheries management legislation (NMFS 2006). The criteria for an area to be identified as basking shark habitat appear to be historic and current records of occurrence of the animals in the location rather than on any recognized characteristic or quality of the habitat itself.

Breeding habitat

Basking sharks are known for their tendency to appear seasonally in large aggregations in particular localities where they are observed intermittently over several months before disappearing again (Squire 1990; Darling and Keogh 1994; Compagno 2001). In British Columbia, anecdotal and newspaper accounts also indicate that several bays and small inlets were noteworthy for the regular occurrence of high densities of basking sharks, and further south along the US Pacific coast only two bays in California have historically hosted aggregations of basking sharks. These aggregations may reflect some unknown breeding or foraging behaviour (Harvey-Clark *et al.* 1999; Sims *et al.* 2000). The qualities or characteristics that attract basking sharks to these areas are unknown.

There is evidence that basking shark populations may segregate spatially and seasonally by sex and/or maturity. Watkins (1958) found that most basking sharks caught in Scottish (95%) and Japanese (65-70%) surface fisheries were female. Compagno (2001) reported that in fisheries off the United Kingdom, basking sharks were most frequently taken in summer and of these the majority were females (97.5%) whereas in winter they were uncommon and those that were caught were mostly males (unknown %). Lien and Fawcett (1986) reported that more males than females were caught incidentally in the inshore waters of Newfoundland. Males dominated all incidental catches of basking sharks by trawlers in New Zealand and while some were large enough to be mature, most were probably immature (Francis and Duffy 2002). Most of the females caught were not thought likely to be big enough to be mature. Globally, there is an absence of pregnant specimens reported, which might indicate a spatial or bathymetric segregation of breeding and non-breeding members of the population. Alternatively, the absence of records of pregnant females may simply reflect the low reproductive capacity of the species. In Clayoquot Sound, Darling and Keogh (1994) identified two males by the presence of large white claspers hanging from the pelvic region.

Nursery habitat

Basking sharks are rarely encountered until they have reached 3 m in length. Size at birth is estimated to be between 1.5 to 1.7 m; the smallest free-living individual was captured off the British Isles and measured 1.65 m (Compagno 2001). Seven basking sharks measuring between 1.25 m and 1.83 m have recently been recorded in the Atlantic observer database (Campana pers. comm. 2007). Recent observations by the UK Marine Conservation Society report that 3% of the 3,300 individuals sighted were less than 2 m long, and 34 % were between 2 and 4 m, all of which were likely immature based on size (Pollard 1996 in Compagno 2001). Off the east coast of Canada, 2.6 % (9 individuals) of the sharks caught incidentally during 1980-1983 were immature and these measured 1.8-3.9 m (Lien and Fawcett 1986). The paucity of recorded occurrences of pregnant females or juveniles in the northeast Pacific Ocean and elsewhere in the world makes it impossible to define nursery habitat for these fish. Little is known of nursery habitats for most temperate water sharks although shark habitat studies in the Pacific Ocean carried out by the Southwest Fisheries Science Center in California and the Cooperative Atlantic States Shark Pupping and Nursery Survey of the US Federal and State government agencies aim to remedy this situation (NEFSC 2007; SWFSC 2007).

Late juvenile and adult habitat

Little is known about age segregation in basking sharks or how it relates to habitat. The only evidence for age segregation in basking sharks comes from New Zealand where immature males were found to predominate in incidental trawl catches in one fishing area during spring/summer (Francis and Duffy 2002).

Additional critical habitat factors

Habitat choice may be related to prey availability and composition but the compositional preferences in zooplankton prey of basking sharks on the Pacific coast of Canada or elsewhere in the northeast Pacific are unknown. Basking sharks occupying southwest England were found to search out patches of zooplankton in which the calanoid copepod *Calanus helgolandicus* predominated, and where they were 50% longer than elsewhere (Sims and Merrett 1997).

Dispersal/migration

Historical abundances and recent sightings of basking shark have been reported off the coasts of British Columbia and California (Figures 1 and 2). Their range extends from the Aleutian Islands in Alaska to Baja California and the northern Gulf of California in Mexico, but little is known regarding the dispersal and migratory patterns of individual basking sharks (Compagno 2001; Appendix B). Satellite tagging may provide answers about dispersal and migration where conventional tagging has not, because although about 146 basking sharks were tagged off California between 1991 and 2007, none have been recovered (Appendix B). Genetic identification and analysis of animals might also enable differentiation between discrete groups of basking sharks in the northeast Pacific, but the only genetic study to date has not included any specimens from the region (Hoelzel *et al.* 2006).

Seasonal migrations are suspected to occur from deep to shallow water or from lower to higher latitudes based on seasonal changes in abundance on both the Atlantic and Pacific coasts of North America. In the northeast Pacific, basking sharks were visibly most abundant in spring and summer off British Columbia and Washington, and off California in autumn and winter. It has been inferred from these observations that there is a single northeast Pacific population that migrates seasonally (Compagno 2001). Many species of large sharks move north along the Atlantic and Pacific coasts of North America in the spring with warming temperatures, and south again in the fall as water temperatures become cooler. Researchers participating in the Tagging of Pacific Predators (TOPPS) project of the Census of Marine Life have tagged sharks and other marine specie which illustrate this seasonal movement (http://topp.org).

Off the US Atlantic seaboard, similar seasonal appearances of basking sharks moving from south to north between spring and summer suggest an annual latitudinal migration. Recent tracking studies of three basking sharks in the northwest Atlantic provide evidence for strong latitudinal movements southward associated with a change in seasons from late summer to winter (Skomal 2005; Skomal *et al.* 2004). However, three satellite-tagged sharks in the northeast Atlantic (UK) tracked for 162, 197, and 198 days did not exhibit any strong latitudinal migration between seasons but rather horizontal movements associated with the continental shelf (Sims *et al.* 2003b). A recent study (Gore et al. 2008) reported on a basking shark tagged with a pop-up archival tag (PAT) off the British Isles released its tag off Newfoundland, Canada. The shark transited a distance of 9589 km and reached a record depth of 1264 m. This study

provides the first evidence of transoceanic migration of basking sharks, and has significant implications for species conservation (recovery from other areas), given an estimate of population size of only 8200 individuals globally (Hoelzel et al. 2006). Amongst white sharks and whale sharks some individuals are also known to undergo lengthy horizontal return migrations while others show fidelity for feeding areas (Environment Australia 2002; DEH 2005).

Habitat trends

Habitat availability for this species is not likely to have changed. Basking sharks are often associated with humpback whale, *Megaptera novaeagliae*, distribution both historically (Wallace and Gisborne 2006) and more recently (Newton pers. comm. 2007). Humpback whale distribution has not changed and abundance has recently increased so it is unlikely that basking shark distribution has been affected by habitat change (COSEWIC 2003).

New evidence from basking sharks studied off England suggest that the sharks target areas of high zooplankton concentrations associated with both large and small scale oceanographic conditions that change quickly (i.e. lasting hours to days) (Sims and Quayle 1998). Longer-term trends in climate may influence prey availability but recent theoretical work suggests that basking sharks can achieve a net energy gain under moderate (0.48-0.70g m-3) concentrations of prey (Sims 1999). Fluctuations in abundance or avoidance of historic seasonal areas of surface feeding may be associated with fluctuations in zooplankton abundance as found for basking sharks off west Ireland (Sims and Reid 2002), or changes in sea surface temperature driven by global weather patterns as observed off southwest Britain between 1988 and 2001 (Cotton *et al.* 2005).

Habitat protection

All habitat of basking sharks in Canada falls under federal jurisdiction managed primarily by Fisheries and Oceans Canada (DFO). At present, there is no intentional protection for basking shark habitat. In Pacific Canada, waters adjacent to Pacific Rim National Park (Broken Group and West Coast Trail components) are areas where basking sharks were sighted historically. Present restrictions in these waters would not afford much protection against perceived threats (i.e. vessel collisions, entanglement in fishing gear and salmon farming net pens).

4. Residences

SARA s. 2(1) defines Residence as "a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating." Currently the policy for designation and protection of residences under SARA is still being developed. The concept of residence as defined above does not explicitly apply to basking shark, which is an open ocean highly migratory fish.

5. Recovery targets

Recovery goal

A short-term goal for the basking shark recovery plan is to promote the population's recovery such that it can be downlisted from Endangered to Threatened. An interim goal is to see positive growth in the basking shark population, perhaps reaching the number of observations (average annual kills) recorded for the 1945-1970 period, i.e. 40 per year. This would be the equivalent of rebuilding to the long term mean CPUE. A long-term goal is be to promote the long-term viability of a naturally-reproducing population and to ultimately remove basking shark from the list of Endangered and Threatened Wildlife and Plants.

Recovery objectives

A production model was used to assess the recovery potential of the Pacific population of basking sharks (see Appendix C for details). Three sets of recovery objectives or targets were assessed:

1. 1000 breeding pairs (Allendorf and Ryman, 2002) assuming that the population has a 50:50 sex ratio distribution. The population simulation was run with a range of assumptions of the proportion of the population that was mature from the year 2007 onwards:
    a. 25% mature
    b. 30% mature
    c. 40% mature
    d. 50% mature
    e. 75% mature

Population attains 99% of the unfished population size ($\hat{N}$) expressed as number of individuals (assumed to be equal to abundance estimated for 1920 i.e. pre-exploitation) and 30%, 40% and 50% of $\hat{N}$ (30% is the biological reference target above which COSEWIC considers a population to be Threatened (i.e. not Endangered), while 40 % is the level above which DFO considers a population to be in a healthy zone 50% of $\hat{N}$ =the population size which theoretically produces the maximum sustainable yield [$\hat{N}_{MSY}$]). Often $\hat{N}_{50\%}$ is used as a definition of carrying capacity.

2. Population attains 30%, 40%, 50% or 99% of the initial biomass ($\hat{B}$) prior to exploitation (assumed to be the biomass in 1920, i.e. pre-exploitation).

Recovery potential was estimated as the number of years required for the population to attain the above recovery objectives under four possible levels of future human induced mortality:

1. No human induced mortality (i.e. fishing mortality (F) =0)
2. F=0.05·M (where M (natural mortality) = 0.068 [Pauly, 2002])
3. F=0.5·M
4. F=M

For all simulations in our base case scenario, it was assumed that the Pacific population of basking sharks had declined by 90% from 1920 (pre-exploitation) to 2007. The model estimates the likelihood that the population was depleted by 90%, and uses

this function when resampling the population of trajectories for estimating the 95% confidence intervals. In addition all simulations use our best estimate of r_{max} (0.032 – 0.04). For alternative depletion scenarios and estimates of *M*, see Appendix C. For all simulations, two catch histories were evaluated:

Catch history 1: A **minimum** history for catches in Canada and the US, consisting of 3,725 individuals killed between 1920 and 1979. Catches in Canadian waters are estimated at 40 fish per year for 1945-1969 (total 1000 individuals) as estimated in COSEWIC (2007). Catches in US waters are estimated at 25 fish per year for 1920-1945 (low exploitation commercial fishery), 200 fish per year for 1946-1952 (high exploitation commercial fishery), and 25 fish per year for 1953-1979 (sports fishery only) as estimated in COSEWIC (2007).

1. ***Catch history 2***: A **maximum** history for catches in Canada and the US, comprised of 5,925 individuals killed between 1920 and 1979. Catches in Canadian waters are estimated at 100 fish per year for 1945-1969. Catches in US waters are estimated at 100 fish per year for 1920-1945, 300 fish per year for 1946-1952 and 100 fish per year for 1953-1979. These represent either the upper range of estimates or the maximum annual catch estimated in COSEWIC (2007).

For each of these catch histories, F in years with no catch specified was randomly selected from F=0 or F=0.05·M to represent human induced incidental mortality.

6. Prognosis with no further human impacts (natural scenario)

Given the lack of knowledge of current abundance, migratory behaviour and range, or on the impact of past and present human activities, there is great uncertainty in any projections that can be made for the future of the basking shark population in Pacific Canada. Slow growth rate, late age of maturity, long gestation period, and probable low fecundity all contribute to the susceptibility of basking sharks to over exploitation and contribute to slow population recovery (Compagno 1984). The likelihood of a rescue effect from US waters is considered low because abundance in US waters is also depleted. If a breeding population currently exists in the northeast Pacific Ocean, and no further human human-induced mortality and changes to existing habitat occurs, the production model estimates that some 200 years are needed before population numbers will return to their unexploited states (Appendix C). If these animals are afforded complete protection, it will still take hundreds of years for the population to recover to 1000 breeding pairs. Recovery to 30% of the original biomass could happen within 45 years if complete protection is afforded. The UK Biodiversity Group has similarly estimated that for basking sharks in the northeast Atlantic, an unexploited population increase may be 2-10% per annum as has been calculated for other large, slow-growing sharks, and that recovery after exploitation and other population fluctuations would require decades (UKBAP 2007).

Assuming estimates of *M* that are ±20% of the default value of 0.068 does not significantly alter our estimates of recovery times. If we assume greater (95%) or lesser (85%) levels of depletion from historic biomass, the unfished population size changes only by ± 1% , resulting in a change in recovery times of less than ±15%.

PHASE 2 – SCOPE FOR HUMAN-INDUCED MORTALITY

7. Threats to basking sharks (as individuals)

Basking sharks are particularly vulnerable to human-induced mortality because of their late age of maturity, low fecundity, long gestation period, long periods between gestations, low productivity, sex segregated populations, use of habitat that supports commercial fisheries, lack of fear of vessels, and current small population size. Like whale sharks, *Rhincodon typus*, basking sharks return regularly to the same seasonal feeding locations. Tagged individuals have revisited some sites in California (e.g. Monterey Bay) and in the UK (Sims *et al.* 2003b; CMS 2007; Van Sommeran pers. comm. 2007). This tendency to be site-faithful, or philopatric makes the species particularly vulnerable to localised depletion. There is considerable doubt whether even moderate exploitation pressure on basking sharks can be sustained (Compagno 2001), and the ramifications for further erosion of already low genetic diversity worldwide is considerable (Hoelzel *et al.* 2006).

Human-induced mortality in Pacific Canadian waters is primarily from continued interactions with fishing gears. Records indicate that basking sharks are readily caught in gillnet but also by trawl (bottom, midwater, and shrimp), and easily become entangled in longlines, prawn traps, cod traps, and even herring seines (Wallace and Gisborne 2006). In any given year between 1942 and1969 several hundred gillnetters fished in these core areas of Barkley Sound and Rivers Inlet, and it is suspected that several hundred sharks (400-1500) may have been killed from entanglement during that time (COSEWIC 2007). Evidence of entanglements in passive gears such as drift and set nets indicates the potential danger of aquaculture net pens (Darling and Keogh 1994; Appendix B).

Historical fisheries and the directed eradication program appear to be the most likely causes for the low abundance of basking sharks observed today in Canada's Pacific waters. There have been few confirmed sightings or catches in recent times. Only four basking sharks have been captured (and presumably killed) since 100% observer coverage of the groundfish trawl fishery began in 1996 (COSEWIC 2007). In Clayoquot Sound there have been three reports of entanglement, one with prawn gear (1988), one in a herring seine (1992), and one in a salmon gillnet (1992) (Darling and Keogh 1994). Despite the few recent instances of mortality, fisheries interactions remain a concern because of the decline in the number of basking sharks. In fact, most basking sharks sightings are now associated with incidental capture.

The likelihood that the basking sharks that visit the Pacific coast of Canada and other basking sharks in the northeast Pacific comprise a single population calls for any actions taken to protect and promote the survival of the species to recognize the importance of impacts on basking sharks beyond Canada's borders. In the Pacific Exclusive Economic Zone (EEZ) of the United States, only five basking sharks have been recorded as bycatch by observers of various fisheries operating since observer programs began: two in the California/Oregon drift gillnet fishery for swordfish and sharks from 1990 and 2006 (i.e., one in 1992/1993 and one in 2002/2003); two from 2001 to 2006 in the California small mesh set net fishery; and one in 2003 in the 1994 to 2007 Hawaii-based surface set longline fishery (NMFS *et al.* 2007; Appendix B). Except for these and the Alaska groundfish trawl fishery, most other US fisheries that have

observer coverage only recognize a few species of shark, placing the rest in a general shark category or the databases have a general shark category and no specific 'code' for basking shark.

Some 54 basking sharks were estimated to have been caught annually in the flying squid and large mesh gill net fisheries of the north Pacific (Bonfil 1994). These estimates are based on a single year of observer coverage (approximately 4.5% coverage of the squid fishery and 6.2% of the large mesh net fishery) by the International North Pacific Fisheries Commission in 1990. By international agreement, drift gill nets have not legally fished in the North Pacific since 1992. However, illegal drift net fishing continues, as was substantiated in September 2007 when a Canada-US aerial patrol identified 10 boats suspected of drift net fishing illegally in the international waters of the North Pacific (Anonymous 2007). Despite the prohibition on shark finning in many countries, including Canada and the US, and against trade in basking shark products (CITES 2007), a basking shark may be too great a treasure for fishers to release when caught incidentally, with a large fin fetching a possible value of $57,000 US (Clarke 2004a *in* Magnussen *et al.* 2007). Evidence of this was recently revealed when a newly developed genetic forensics assay was used to identify mislabelled basking shark fins in the possession of a large seafood dealer in the US and in markets in Japan and Hong Kong (Magnussen *et al.* 2007). The continued market demand for basking shark fins will persist in driving exploitation and trade, covertly and otherwise, and the true extent of the exploitation as is reflected in official trade reports to CITES will be an underestimate.

Harassment, sometimes lethal, has also been mentioned in historic anecdotes and the behaviour may appear again if basking sharks return in numbers to Canada's Pacific coast (Wallace and Gisborne 2006). Tourism is not an issue for basking sharks at this time but, as has become apparent in the whale watching industry, if basking sharks do increase off the coast of British Columbia, then protocols to minimize disturbance and prevent harassment of the animals may need to be implemented (Lien 2007).

Collisions between marine vessels and basking sharks have been recorded historically (Wallace and Gisborne 2006) and the extent of the scarring of fins and snouts observed more recently by Darling and Keogh (1994) on basking sharks in Clayoquot Sound suggest that altercations between boat propellers and basking sharks may be common. The habit of the animals of feeding slowly at the surface in shallow water increases the likelihood of this occurring.

The effects of very loud sounds on shark behaviour are not well documented but some recent evidence suggest that they could potentially disrupt normal behaviours such as feeding, mating, or migrating from one place to another. Although sharks do not use sound to communicate with each other in the way of cetaceans, they do sense sound as pressure through their lateral line system, and have been shown to detect sounds with frequencies ranging from 10 Hertz to 800 Hertz (Martin 2004). The apparent attraction of basking sharks to boat propellers, possibly to the sound they generate, may contribute to boat-shark interactions that have led to considerable scarring on the fins and snouts of sharks (Darling and Koegh 1994).

There are very few predators of adult basking sharks but some individuals have been observed to fall prey to great white sharks, *Carcharodon carcharias*, although

these incidents may have been examples of opportunistic scavenging by the great white sharks on fish that had already been harpooned rather than active predation (McCosker 1985).

Concerns about potential contamination and bioaccumulation of organic pollutants and heavy metals in marine organisms, particularly long-lived cetaceans, also extend to basking sharks. High levels of DDT have been found in fins whales, *Balaenoptera physalus*, in the Mediterranean, and levels of mercury, cadmium, and certain organochlorines detected in the tissues of sperm whales, *Physeter macrocephalus*, in western Europe were high enough to cause concern (Fossi *et al.* 2003). While the levels of organochlorines, other organotoxins, and heavy metals in baleen whales generally are not considered high enough to cause toxic or other damaging effects, little is known about the possible long-term and trans-generational effects of exposure to pollutants (O'Shea and Brownwell 1995). Baleen whales and presumably basking sharks that feed low in the food chain are unlikely to bioaccumulate contaminants as are higher trophic level animals such as killer whales, *Orcinus orca* (Hickie *et al.* 2007). However, indirect impacts of pollution on the planktonic food items of basking sharks could cause local depletion of prey species resulting in a shift in habitat use due to food scarcity.

Food, social, and ceremonial fisheries - Currently basking sharks are not exploited for food, social and ceremonial fisheries. Historically, First Nations may have exploited basking sharks for their liver oil, particularly when the sharks were in a moribund state or were stranded (Dawson 1880).

Research and recovery activities - Currently basking sharks are not encountered during research surveys. Basking sharks could be captured incidentally in research surveys, but there is the potential to release them alive. Recovery activities do not require the capture of basking sharks.

8. Threats to habitat features

No critical habitat, as such, has yet been identified, but basking sharks tend to remain within a thermal regime and aggregate for surface feeding where frontal areas create high zooplankton productivity at the surface. If climate change leads to higher sea surface temperatures, if altered winds and ocean currents change patterns of upwelling, and if oceans become more acidic as concentrations of dissolved carbon dioxide increase, then these frontal areas of high zooplankton productivity may be affected. Basking sharks may be particularly vulnerable to environmental changes because of very low genetic diversity (Hoelzel *et al.* 2006). Zooplankton production may also be compromised by any marine pollution that may be contributed by coastal development activities.

The importance of zooplankton abundance to a planktivorous fish that is estimated to be capable of filtering more than 2000 tonnes of seawater per hour should not be undervalued (Compagno 1984). An average stomach may contain half a ton of planktonic organisms, i.e. small copepods, barnacles, decapod larvae and fish eggs. Basking sharks are unlike the other filter-feeding sharks, i.e., whale sharks and megamouth sharks, *Megachasma pelagios*, in that feeding is entirely passive, with the flow of water over the gill rakers entirely due to the slow swimming speed of less than 2 knots. Feeding appears to be random when plankton densities are low but where high

densities of zooplankton are available, such as along tidal fronts, the search for minimum concentrations becomes more active and feeding is highly selective (Compagno 2001).

There is no evidence for competition between basking sharks and baleen whales for preferred zooplankton on the Scotian Shelf (Clapham and Brownell 1996). However, the potential for negative impacts on fish and baleen whales from competition with humans for zooplankton has been recognized by the states of Washington, Oregon, and California, which prohibit their vessels from fishing for krill and prohibit landings of krill in their respective ports. A fishery for krill (i.e. a selection of zooplankton made up of several species of Euphasiids) has operated in the Strait of Georgia and several mainland inlet areas of British Columbia with a Total Allowable Catch (TAC) of 500 tonnes since 1990 (DFO 2007a). Currently, most of the landings occur in late fall and early in the new year which means that any competition that could arise between basking sharks and the fishery would be minimal. The fishery also does not currently operate in any of the inlet areas (i.e. Barkley Sound, Clayoquot Sound, Rivers Inlet/Queen Charlotte Sound and Smith Inlet) where aggregations of basking sharks have been observed historically.

Structural elements of marine development like fish farm pens, log booms, and debris may obstruct access to or otherwise compromise traditional visiting/feeding grounds.

9. Scope for total allowable harm

The production model simulations (Appendix C) for our base case scenario produced population trajectories (with 95% confidence intervals) from 2007 onwards for four scenarios of future human induced mortalities:

1. no human induced mortality (i.e. fishing mortality (F) =0)
2. $F=0.05 \cdot M$ (where M (natural mortality) = 0.068 [Pauly 2002])
3. $F=0.5 \cdot M$
4. $F=M$

For all recovery objectives, assumptions and catch histories that were explored, the population becomes extinct within 30-40 years under future human induced levels of mortality $F=0.5 \cdot M$ and $F=M$ (Figure C-3 in Appendix C). This suggests that a targeted fishery for basking shark or extreme high levels of incidental catch do not fall within the scope for total allowable harm. High levels of incidental catch will only be an issue at higher densities of basking shark and the model results here suggest that if basking shark densities increase such that incidental catch is high, then avoidance measures must be put in place rapidly to avoid extinction. At the lower abundance estimate for 2007 of approximately 321 sharks (based on catch history 1), and M=0.068, the shark mortality in numbers of fish per year for $F=0.5 \cdot M$ and $F=M$ would be 11 and 22 sharks per year respectively. This mortality in numbers of fish per year would be 18 and 36 respectively for catch history 2. This number of sharks caught and killed per year would be a total for the Canadian and US waters. Since these two scenarios result in extinction within 30-40 years, they are not discussed below for the recovery objectives.

The total allowable harm will depend on the recovery objective selected, the acceptable time to recovery and the assumed catch history (Table 1). The two catch

histories reflect the minimum historic catch and the maximum historic catch and there is no reason to accept one catch history over the other.

Table 1: The recovery potential (years to attain recovery objective) given each catch history and future human induced mortality (F) scenarios for each recovery objective.

	Recovery potential (years)			
	Catch history 1		Catch history 2	
Recovery Objective	**F=0**	**F=0.05·M**	**F=0**	**F=0.05·M**
1. 1000 breeding pairs				
a. 25% mature	500+	500+	500+	500+
b. 30% mature	500+	500+	500+	500+
c. 40% mature	500+	500+	500+	500+
d. 50% mature	500+	500+	105	146
e. 75% mature	122	500+	66	79
2. Proportion of unfished abundance ($\hat{N}$)				
a. $\hat{N}_{30\%}$	37	43	37	42
b. $\hat{N}_{40\%}$	50	58	49	57
c. $\hat{N}_{50\%}$	61	72	60	71
d.99%of $\hat{N}$	189	Never	188	Never
3. Proportion of unfished biomass ($\hat{B}$)				
a. 30%	46	53	46	52
b. 40%	59	69	58	67
c. 50%	70	83	69	82
c. 99%	196	Never	195	Never

1000 breeding pairs: Additional modelling efforts using an age-structured model (Appendix C) suggested that approximately 40% of an unexploited basking shark population is mature, which suggests that this is a useable assumption in the production model trajectories. At 40% mature, it would take at least 500 years to attain 1000 breeding pairs of basking sharks with a 50:50 sex ratio for both F=0 or F=0.05M levels of human induced mortality. At 2007 abundance estimates, F=0.05·M is approximately 1 shark per year based on catch history 1, or 2 sharks per year based on catch history 2.

Proportion of unfished abundance ($\hat{N}$): At low levels of human-induced mortality (F=0.05·M) basking sharks will never attain 99% of pre-exploitation abundance ($\hat{N}$). However, modeling results suggest attaining a $\hat{N}_{50\%}$ that corresponds to the number of sharks that would produce maximum sustainable yield ($\hat{N}_{MSY}$) could occur from 60-61 years (if F=0) to 71-72 years (if F=0.05·M). $\hat{N}_{30\%}$ could be reached in 37 years (F=0) to 43 years (F=0.05·M). There is virtually no difference in recovery potential between catch histories.

Proportion of unfished biomass ($\hat{B}$): As with the carrying capacity recovery objective, at low levels of human-induced mortality (F=0.05·M) basking sharks will never attain the biomass estimated by the model for pre-exploitation ($\hat{B}$). The production model simulation suggests that the basking shark population can attain 30% of $\hat{B}$ in 46 years (F=0) to 52-53 years (F=0.05·M). The basking shark population can attain 40% of $\hat{B}$ in 58-59 years (F=0) to 67-68 years (F=0.05·M). To attain 50% of $\hat{B}$ would require 69-70 years (F=0) to 82-83 years (F=0.05·M). There is virtually no difference in recovery potential between catch histories.

The fishing mortality rate that the population can sustain without suffering further decline from the 2007 population size is 0.032 (0.031 – 0.032) or 47% (46-47%) of the natural mortality rate (Appendix Table C - 5). This is the case for both catch histories 1 and 2. In terms of numbers of basking sharks killed annually it is 10 (1-21) for catch history 1 and 17 (2-34) for catch history 2 (Appendix Table C - 5).

It is important to note that the production model simulations utilize catch history scenarios that combine Canadian and US exploitations. In addition, the basking shark population that was observed in Canadian Pacific waters in summer is assumed to be the same population observed in US Pacific waters in winter. As such, the total allowable harm represented in the model simulations and discussed here applies to human induced mortality summed for both Canadian and US Pacific waters.

It is also important to note that varying *M* by ±20% and changing the estimate of historic depletion from the base case (90%) to a greater (95%) or lesser (85%) level of depletion, resulted in little change to recovery times under any of the recovery potential scenarios (Appendix C).

PHASE 3 – SCENARIOS TO PROMOTE RECOVERY

10. Restrictions on human-induced mortality

Although interactions with fisherman have been few in recent years, the numbers are high considering how few basking sharks have been sighted at all. From 1994 to 2006, only 7 basking sharks sightings could be confirmed in the coastal waters of BC and of these 4 were from observer records of the groundfish trawl fishery, while along the coast of California sightings of some 24 individuals have been reported and of these 3 were from observer records of the California drift gill net and set net fisheries (Appendix B; COSEWIC 2007). If the abundance of basking sharks in the coastal waters of the Canadian Pacific increases then the conflicts that were seen from the 1920s to the 1960s might return.

Entanglement and bycatch in fishing gears can be expected, and steps must be taken to reduce the likelihood of damage and loss to both fishermen and sharks. In order to achieve no human-induced mortality due to entanglement or incidental bycatch, a complete revision to fishing gear and/or fishing plans would be required. This could include changes to fishing plans such as time/area closures, automatic closures based on historical distribution patterns or closures triggered by some level of interaction between sharks and fishing gear. Alternatively, modification to fishing behaviour could

minimize entanglement or incidental bycatch. For example, if a basking shark is sighted at the surface, then fishing gear would not be set or hauled back until the shark has left the vicinity. Fishing behaviour modification might be achieved through voluntary participation, i.e. education programs, rather than involuntary participation, i.e. fishing plans. This would alleviate the requirement for such a large scale fishery closure.

It is likely that the basking sharks that visit Canadian Pacific waters are of the same population of animals that travels to the coast of California. It is not known if these sharks are related to those caught in high seas drift net fishing in the North Pacific. If sharks from elsewhere in the North Pacific are to create a rescue effect for sharks in coastal BC then these animals also need protection. The United States has protected basking sharks by designating them as a Prohibited Species under the Fishery Management Plan (FMP) for US West Coast fisheries for Highly Migratory Species (HMS) which was adopted in June of 2007 (PFMC 2007). This was an extension of an earlier version of the FMP that had been in effect since 2004. A prohibited species must be released immediately if caught, unless other provisions for its disposition are established, including scientific study. Retention of basking sharks had been banned since 2000 in California state waters by the Department of Fish and Game (CDFG 16-8599.4) (Bizzarro, pers. comm. 2007). There are currently no similar explicit bans in place in Oregon or Washington; however, provisions for basking shark disposition as a prohibited species have not been made in these states. Canada and the United States already contribute to enforcement of the prohibition on high seas drift net fishing in the North Pacific, and thereby contribute to reducing the level of mortality of basking sharks and other bycatch and discard animals. Unfortunately, the recent interception of boats in the North Pacific that were possibly drift net fishing demonstrates that the international community cannot relax its vigilance and might consider increasing it (Anonymous 2007).

Trade in basking shark products was prohibited in many United Nations member states after it was listed on Appendix II of the Convention on International Trade in Endangered Species (CITES 2002). While this action curbs trade, and therefore exploitation, it does not unfortunately prevent it completely, as is proven by the recent identification of basking shark fins in the possession of a large seafood trader in the United States and markets in Hong Kong and Japan (Magnussen *et al.* 2007). The new technique developed to identify basking shark fins that are illegally labelled as legitimately tradable species aids in the battle to inhibit the illegal trade in basking shark products. Canada already has legislation in place that prohibits any processing at sea for any shark species, thereby restricting shark *finning*, i.e. the practice of removing the fins and discarding the remainder of the carcass while at sea. Canada should continue to encourage other nations to prohibit the sale or trade of basking shark fins and other products.

Because even moderate exploitation of basking sharks probably cannot be sustained, reliable information on the current level of exploitation is essential for planning effective management and conservation strategies. The imprecise reporting of fishery statistics where several species are lumped together as one category, i.e., "other sharks" can mask reduction in populations of larger, slower growing species like basking sharks, as well as obscuring changes in community structure (Dulvy *et al.* 2000). Expansion of observer programs to all fisheries with the potential to entangle basking sharks, and improvement of species identification and reporting in current observer programs could be granted priority similar to cetacean programs.

Historical stories of harassment and collisions, and more recent observations of scarring on the dorsal fins of basking shark possibly from boat propellers, indicate the potential for mortality from contact with boats. A program of public education encouraging responsible boat handling in the vicinity of basking sharks similar to the guidelines and best practices for whale watch operators in BC (WWOANW 2007) could be adopted, particularly the minimum approach distance of 100 metres/yards recommended for whales and other marine mammals.

Many of the changes and improvements in fisheries data collection and bycatch management mentioned here have been proposed in the draft National Plan of Action (NPOA) for the Conservation and Management of Sharks of February 9, 2007 (DFO 2007b):

- Improve the reporting of discarded bycatch and the associated mortality rates in domestic fisheries through better data collection and species identification by at-sea fisheries observers and through mandatory reporting of all bycatch for the commercial and recreational fishing industry;

- Continue awareness-raising efforts among commercial and recreational fishers and other resource users about the risks facing certain shark and shark-like species and promote conservation-based release practices to reduce discard mortality;

- Encourage the strengthening of regulations of relevant Regional Fisheries Management Organizations with regard to both the handling and release of shark bycatch species and to improve the identification and reporting of bycatch and associated mortality; and

- Review the current practices in all commercial and recreational fisheries and implement, where feasible, new rules or technologies with the potential to reduce both the bycatch of sharks and associated mortality.

Food, social, and ceremonial fisheries – Basking sharks are depleted to such an extent that there should be no allowable targeted fisheries. Reduction in entanglement and incidental bycatch while conducting other targeted fisheries for food, social and ceremonial purposes could be achieved through fishery behaviour modification suggested above.

Research and recovery activities - Reduction in entanglement and incidental bycatch during research surveys could be achieved through fishery behaviour modification suggested above.

11. Mitigating threats

Mitigating threats to habitat

The first step in mitigating any threats to the habitat of basking sharks is to identify the preferred habitat, perhaps simply by outlining the areas of historic aggregations. On the Pacific coast of Canada, the areas in which high abundances have been recorded are Rivers Inlet, Clayoquot Sound, and Barkley Sound. However, this might reflect a lack of historical observations in other areas, rather than a historical

absence of basking sharks from other areas, and if basking sharks recover they may show up in remote coastal inlets. Designation of these areas as critical habitat for basking sharks would contribute to awareness and allow for implementation of location specific measures to protect the animals and their habitat. Coastal development in these areas could then be managed to prevent or minimize impacts on basking sharks by taking such steps as: avoiding placement of marine structures, i.e. aquaculture pens, in migration routes/feeding paths; minimizing boat traffic during seasons of peak abundance; preventing marine pollution from sewage, runoff and debris.

Efforts should be made to cooperate with the US government to recognize and protect basking shark habitat within our respective national borders, and to join multinational efforts on behalf of marine habitat protection.

Characterization of habitat that is used intensively by basking sharks and how the areas are used, e.g., seasonal feeding, mating, pupping or rearing, is essential for providing protection. Defining characteristics such as types, densities, and abundances of prey and how they are associated with oceanographic and hydrographic features would help to define components of critical habitat. Determining inter-annual variability in basking shark habitat use and habitat characteristics will contribute to development of a predictive framework for identifying potentially important basking shark habitat.

Studies designed to improve knowledge of basking shark feeding ecology such as prey preferences, dietary requirements, and energetics, are important to understanding habitat use and the impacts of fishery practices and fluctuating food-web dynamics on shark populations. Consumption of zooplankton by basking sharks in areas of particularly high productivity means that they will interact in important ways with commercial fisheries through sharing feeding habitat with other marine species in many areas. The vulnerability of basking sharks to any persistent climate changes needs to be highlighted in research for management of marine ecosystems. Basking sharks might respond to changes in prey abundance and distribution by shifting summer and winter feeding activities to new inlets and bays which could expose them to new threats.

Most of the 500 tonnes of krill caught in the directed fishery that operates in the Strait of Georgia and several mainland inlet areas of British Columbia is landed in late fall and early in the new year in areas not known for aggregations of basking sharks. Competition that could arise between basking sharks and the fishery would be minimal. However, this could be ensured by applying seasonal restrictions on the krill fishery, particularly if any consideration is made to expand the fishery to any location in which basking sharks were known to aggregate in the past. The significance of krill to economically important fish species as well as the entire marine ecosystem has been recognized by the states of Washington, Oregon, and California, which prohibit their vessels from fishing for krill and prohibit landings of krill to their respective ports. Comprehensive federal legislation drafted by the Pacific Fisheries Management Council that would prohibit any harvesting of krill within the Exclusive Economic Zone of the United States west coast is currently under consideration (NMFS 2007).

Mitigating threats to individuals

The ongoing development of ecotourism on the Pacific coast of Canada means that basking sharks may be subjected to the same harassment and unintentional disturbance that many whale species have experienced (Lien 2007). A voluntary code of conduct for whale watching in British Columbia has been proposed and versions are

publicised by many operators (WWOANW 2007). Recommendations made for public viewing and the photo-identification project of basking sharks and in the UK are defined in a Code of Conduct provided by the Shark Trust of the UK (available at http://www.manxbaskingsharkwatch.com/code.aspx). The following excerpt of the Code of Conduct provides a template for recommendations that could comprise part of a public information program promoting protection of basking sharks that encourages the same quality of behaviour as has been done for whales.

Boat control near basking sharks

- *Restrict your speed to below 6 knots and avoid sudden speed changes.*
- *Do not approach closer than 100m.*
- *When closer than 100m switch the engine to neutral to avoid injuring sharks.*
- *Avoid disturbing dense groups of sharks as you may disrupt courtship behaviour.*
- *Do not approach areas where basking sharks have been observed breaching.*
- *Jet-skis are incompatible with basking sharks and should stay at least 500m away.*
- *Remember, for every shark visible on the surface there are likely to be more hidden just below.*

Swimming with basking sharks

- *Do not try to touch the sharks.*
- *Maintain a distance of greater than 4m from each basking shark and be wary of the tail.*
- *Avoid entering the water if visibility is less than 4m.*
- *Groups of swimmers must stay together and ideally remain at the surface.*
- *Restrict the numbers of swimmers in the water at any time to 4.*
- *Avoid flash photography as this can scare the sharks.*
- *Do not use underwater-propelled devices.*

Recommendations for both fishers and the public to enhance outreach and education efforts concerning shark species, threats to their survival, and their importance within the ecosystem as outlined in the National Plan of Action for sharks would contribute to awareness and possibly decrease the likelihood of collisions and harassment (DFO 2007b):

- Increase public awareness in Canada about shark species, risks to their survival, their importance within the ecosystem, and the fact that they are often a global resource requiring international research and conservation efforts;

- Encourage commercial and recreational fishers, and other industries to be more aware of the shark species present in Canadian fisheries waters, their biology, risks these species face, and catch-and-release practices through the advisory committee processes; and

- Enhance efforts to classify and record rarer species of sharks and skates, by promoting better identification in existing observer programs and through enhanced reporting by fishers.

There is no evidence that levels of organochlorines, organotoxins, or heavy metals in baleen whales are high enough to cause toxic or other damaging effects, suggesting that levels in the plankton-feeding basking shark are also likely to be of low or no concern (O'Shea and Brownell 1995). However, when possible, tissue samples could be collected and analyzed for organic contaminants and heavy metals in order to test this assumption.

12. Adaptability

All known or inferred life history parameters imply that basking shark populations cannot recover quickly following a reduction in abundance. They may respond to changes in the environment by shifting their distribution to more favourable areas. The population structure of basking sharks may be more complicated than is presently inferred from seasonal migration. Adaptability of basking shark to stressors remains unquantifiable; however, given their failure to recover within 30 years after directed killing ceased, they are not likely able to adapt within the short time period of a single generation. This review indicates that they may be able adapt to time scales of hundred years. Aquaculture or artificial captive breeding is not a feasible option to promote recovery.

13. Suggested research and recovery promotion activities

- Identification of basking shark in surface waters; no setting or hauling of gear while shark is visible in the vicinity.
    - education program for fishing communities
    - web site
    - posters
    - seminars given at advisory groups
    - video
    - press releases

- Creation of DFO managed basking shark sighting reporting network and database. To date, there is no central database that is managed by a single agency with timely access to sightings. DFO is the agency responsible for monitoring and research related to basking shark, and as such should be the agency that is publicized as the contact and authority for basking shark sightings or strandings by the fishing and tourism industries and the general public.
    - phone-in sightings
    - web-based reporting
    - database development and maintenance
    - linkages with US agencies to ensure and promote US stewardship as recovery will require international cooperation

- Aerial surveys for search and enumeration of basking sharks in historic areas of abundance in Canadian waters.
    - conducted May-September when basking sharks migrate to Canadian waters
    - conducted in Barkley Sound, Clayoquot Sound and Rivers Inlet; other areas could be added if sightings are reported for elsewhere

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    - conducted May-September when basking sharks migrate to Canadian waters
    - conducted in Barkley Sound, Clayoquot Sound and Rivers Inlet; other areas could be added if sightings are reported for elsewhere

    - use platforms of opportunity – float plane and marine boat operators
    - incorporate satellite imagery
    - use of existing creel survey overflights and marine mammal aerial surveys

- Coordinate sighting reports to opportunistic research sampling. If possible use of charter or research vessels to investigate basking shark sightings and utilize research opportunities.
    - validate the identification made by fishing industry or general public
    - opportunistic biological sampling on incidental catches
    - opportunistic sampling for genetic work
    - oceanographic sampling (CTD, zooplankton tows) to relate areas of occurrence to habitat characteristics
    - opportunistic satellite tagging
    - dead animals resulting from incidental catches must be landed for biological sampling

- Investigate deterrent devices for fishing gear.

14. Sources of uncertainty

Biological parameters for the Pacific population of basking sharks are poorly understood. More definitive estimates of age, growth rates, and fecundity would increase the reliability of production models.

While all evidence points to a severe decline in basking shark abundance, actual abundance is unknown, and requires that scientifically robust, regular and repeatable population surveys be designed and undertaken.

Better understanding of entanglements and incidental catch of basking sharks in fishing gear, and survival after release would contribute to the design of modifications and improvements to fishing gears that would decrease the likelihood of mortality.

Little is known of the structure and discreteness of the population of basking sharks in Canada's Pacific region or of their genetic relationship to other populations in world. However, analysis of historic migration patterns indicates a single coastal stock from California to British Columbia.

The current range, migrations patterns and routes, and critical feeding, breeding, and nursery habitats need to be better identified to elucidate critical habitat.

It is not known whether there have been any changes in the habitat characteristics that once attracted basking sharks in abundance to selected areas on the Pacific coast of Canada and the US (i.e., Rivers Inlet, Clayoquot Sound, and Barkley Sound in British Columbia and Morro Bay and Monterey Bay in California), and if these changes may have an affect on basking shark abundance at these locations. Changes to these habitats must be identified before any rehabilitation measures can be considered.

Emerging activities that will have an impact on the species and thus on its recovery need to be identified in order to develop appropriate and timely responses.

Identification of the preferred zooplankton prey of basking sharks would be the first step in determining the oceanographic and climatic characteristics that influence its abundance and distribution. Feeding ecology studies would contribute to a predictive model for the ecological impacts of fishing (i.e. other species) and climate change.

Potential impacts of climate change must be explored in order to better prepare future protective measures and rehabilitation plans.

Determining the effect of marine noise including that of boats and propellers on basking shark behaviour would enable the development of more effective measures for protection and might contribute to the design of avoidance devices for fishing gears.

CONCLUSIONS

Information and recommendations provided in this report are based on the best scientific knowledge available. There is little doubt that basking sharks once frequented British Columbia's coast in numbers and distribution much larger than found today (Wallace and Gisborne 2006). For most of the historical record, basking sharks were regularly encountered by mariners. They were described as being *plentiful* and *common* in several early descriptions. The disappearance of local aggregations coincides with known sources of human-caused mortality, which is consistent with experiences from other regions in the world. Where basking shark populations have been observed, annual number of records is at most in the low thousands (Squire 1967; Compagno 2001). The small local occurrence of basking sharks in Clayoquot Sound was the last known aggregation in British Columbia.

There are very few recent surface (i.e., visual observations) or subsurface (trawl observer data) records, indicating that basking sharks are presently rare in British Columbia waters. The best scientific information indicates that the population off the British Columbia coast has declined from a minimum of 750 individuals to virtually none within a span of 60 years (2-3 generations). The US Pacific population has suffered a similar possibly more drastic decline such that no rescue effect can be expected.

Under the assumption that the Pacific population of basking sharks has declined by 90% from 1920 to 2007, catch scenarios predicted by the production model have had a drastic effect on these large, old, slow-growing sharks. In this paper it is estimated that some 200 years are needed before population numbers will return to their unexploited states if human induced mortality is zero. We estimate that these fish will never return to their unexploited state at a low level of human induced mortality (which at 2007 population estimates would equal 1-2 fish killed per year). If these animals are afforded complete protection, it will still take centuries for the population to recover to 1000 breeding pairs. Recovery to 30% of the original biomass could happen at within 45 years. However, even small levels of mortality (i.e. 1-2 fish per year) would push this recovery target a further 10 years into the future. If human induced mortality is allowed to approach 0.5*M* (11-18 sharks per year) the basking shark population will be extinct within approximately 30 years.

Basking shark is a long lived species with a low rate of increase (i.e., Generation time of 22-33 years). The uncertainties in the projections of this report increases with time. To make progress in rehabilitating the basking shark population, will require government agencies to promote research and management activities for decades.

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Appendix A: Biology and Distribution of the Basking Shark, *Cetorhinus maximus* in Canada's Pacific region

Excerpted from COSEWIC 2007 (with additions).

SPECIES INFORMATION

Name and classification

The basking shark (*Cetorhinus maximus* Gunnerus, 1765) is the sole member of the family Cetorhinidae belonging to the order Lamniformes. Other common names include sun shark, bone shark, and elephant shark. In French this species is known as Pèlerin. In Pacific Canada, the basking shark was also commonly but incorrectly referred to as mud shark in early historical accounts.

Morphological description

This animal is most readily distinguished in the field from other sharks by its large size (maximum reported 12.2 m), elongated gill slits which extend almost to the mid-dorsal of the head, pointed snout, a large subterminal mouth with minute hooked teeth, caudal peduncle with strong lateral keels, and crescent shaped caudal fin (Compagno 2001, Figure 1). Colour is typically blackish to grey-brown, grey or blue-grey above and below on body and fins, undersurface sometimes lighter, often with irregular white blotches on the underside of the head and abdomen (Compagno 2001). Internal gill openings have prominent gill rakers formed from modified dermal denticles

Genetic description

The population structure of basking sharks is poorly known. There has been no population genetic work done on this species. Inferences about population structure are based on records of seasonal occurrence and limited observations from tagging studies. In Canada, basking shark populations in the North Atlantic and North Pacific are geographically disjunct and are considered to be reproductively isolated from one another due to their preference for temperate waters that would preclude migration through the Arctic Ocean. In the North Pacific, basking sharks were observed historically in discrete locations off California in winter to spring and in particular areas off British Columbia in summer and fall (Squire 1967, 1990). This information, combined with recent satellite tracking information from the North Atlantic (Sims *et al.* 2003; Skomal *et al.* 2004; Skomal 2005), suggests the possibility of a single panmictic population along the west coast of North America. On the other hand, throughout their global range, basking shark aggregations have been reported to occur repeatedly in discrete areas where they are typically found in large numbers and for only part of the year (Compagno 2001). Thus, philopatry and more complicated genetic population structure may exist.

Designatable units

Given that basking sharks are found exclusively in temperate oceans and that there is no connection through the Arctic or from the south, the species in Canadian Pacific waters is considered to be separate from that in Canadian Atlantic waters and to comprise a separate designatable unit.

Special significance of the species

The basking shark is the only species in its family. The earliest fossil basking shark is 29 to 35 million years old. It qualifies for the category "charismatic megafauna" by virtue of its large size (second largest fish in the world) and conspicuous surface activity. On the Pacific coast basking sharks are the most plausible explanation for sea serpents, sea monsters, and the Cadborosaurus (Caddy). The high value of basking shark fins has promoted a lucrative trade to Asian countries. The recent inclusion of basking shark under Appendix II of CITES (2002) is intended to regulate this trade. The basking shark may be more vulnerable to human impacts than any other marine fish.

DISTRIBUTION

Global range

Basking sharks are found circumglobally in temperate coastal shelf waters but are characterized by localized occurrences (Figure 2), occurring off the coast of fifty countries (Froese and Pauly 2005). In the North Atlantic, basking sharks are observed in waters off countries as far south and east as Senegal, through to Europe (including the Mediterranean Sea), Norway, Sweden, Russia, westward to Iceland, Canada (Newfoundland, Nova Scotia, New Brunswick), along the eastern seaboard of the United States and into the Gulf of Mexico. In the North Pacific, they are observed as far south and west as Japan, through to China, along the Aleutian Islands, Alaska, British Columbia, along the western seaboard of the United States and Mexico (Baja California and northern Gulf of California) (Compagno 2001). Basking sharks have not been observed in equatorial waters.

BIOLOGY

Biological information has been obtained primarily from the work by Compagno (2001) and from a United Kingdom proposal to list basking shark under Appendix II of CITES (2002). Both reports provide a comprehensive review of basking shark biology.

Life cycle and reproduction

The life cycle and reproduction of basking sharks are poorly understood but likely similar to other lamnoid sharks. Pairing is thought to occur in early summer based on observed courtship behaviour (nose to tail circling) and scarring (Matthews 1950; Sims *et al.* 2000). Gestation period has been estimated at 3.5 years by Parker and Stott (1965) and, more recently, at 2.6 years by Pauly (2002) who assumed a length at birth of 1.5 m and a von Bertalanffy growth coefficient (K) of 0.062/year. Information about pregnancy is based on a single basking shark with a litter of six young estimated to be between 1.5 and 2 m in length (Compagno 2001). Like other lamnoid sharks, the basking shark may exhibit embryonic ovophagy, which supplies nutrients to the developing embryos (Compagno 2001). Time between successive litters may be two to three years (Compagno 2001). Longevity is presumed to be approximately 50 years and age at maturity is estimated at 12 to 16 years in males and 16 to 20 years in females (UK 2002). Recent reanalysis of vertebral band pairs in basking sharks related deposition to growth rather than time, thereby calling in to question many of the age estimates for basking sharks (Natanston *et al.* In press). Length at maturity is estimated at 4.6 to 6.1 m for males based on clasper development (Bigelow and Schroeder 1948);

females are presumed to mature at a larger size than males as in many other shark species. Estimates of annual productivity (r_{msy}) range from 0.013 to 0.023 based on the methodology of Smith *et al.* (1998) using age at maturity, maximum age and average fecundity (CITES 2002). This suggests that the potential for recovery (rebound rate) is lower for basking shark than for any of the 26 species of Pacific shark examined by the Smith *et al.* (1998). Pauly (2002) calculated the natural mortality (M) to be 0.068. Based on an age of maturity of 18 years for females (midrange of 16-20 years), the generation time can be estimated as 18+1/0.068=33 years. In contrast, the CITES (2002) reports the generation time as 22 years.

Herbivory/predation

At birth, basking sharks are between 1.5-1.7 m in length, large enough to escape predation by most marine species. Very large predators, such as the white shark and killer whale may kill basking sharks but no such kills have ever been documented.

Physiology

Basking sharks have been recorded in surface waters ranging from 8 to 24°C, with most observations from 8 to 14°C (Compagno 2001). Four sharks tagged with temperature data loggers in the northeast Atlantic were typically found in waters between 9 and 16°C (Sims *et al.* 2003). Basking sharks periodically shed their gill rakers and are presently thought to cease feeding while they regenerate new ones (4-5 months) (Compagno 2001). Their massive livers may act as a metabolic store that maintains energetic requirements while not feeding (Compagno 2001). Recent tagging has largely disproved the longstanding theory that basking sharks 'hibernate' in deep water over the winter (Sims *et al.* 2003).

Dispersal/migration

Very little is known regarding the dispersal and migratory patterns of individual basking sharks. There has been only one conventional tagging study in the North Atlantic and none of the156 individuals tagged was recaptured (Kohler *et al.* 1998).

Seasonal migrations are suspected to occur from deep to shallow water or from lower to higher latitudes based on seasonal changes in abundance on both the Atlantic and Pacific coasts of North America. In the northeast Pacific, basking sharks were visibly most abundant in spring and summer off British Columbia and Washington, and off California in autumn and winter. It has been inferred from these observations that there is a single northeast Pacific population that migrates seasonally (Compagno 2001). Similarly, off the US Atlantic seaboard, seasonal appearances of basking sharks moving from south to north between spring and summer suggest an annual latitudinal migration. Recent tracking studies of three basking sharks in the northwest Atlantic provide evidence for strong latitudinal movements southward associated with a change in seasons from late summer to winter (Skomal *et al.* 2004; Skomal 2005). However, three satellite-tagged sharks in the northeast Atlantic (UK) tracked for 162, 197, and 198 days did not exhibit any strong latitudinal migration between seasons but rather horizontal movements associated with the continental shelf (Sims *et al.* 2003).

There is evidence that basking shark populations may segregate spatially and seasonally by sex and/or maturity. Watkins (1958) found that most basking sharks caught in Scottish (95%) and Japanese (65-70%) surface fisheries were female. Compagno (2001) reported that in fisheries off the United Kingdom, basking sharks were

mostly females (97.5%) when encountered frequently in summer but mostly males (unknown %) and uncommon in winter. Lien and Fawcett (1986) reported that more males than females were caught incidentally in the inshore waters of Newfoundland. Globally, there is an absence of pregnant specimens reported, which might indicate a spatial or bathymetric segregation of breeding and non-breeding members of the population. Alternatively, the absence of records of pregnant females may simply reflect 13 the low reproductive capacity of the species. In Clayoquot Sound, Darling and Keogh (1994) identified two males by the presence of large white claspers hanging from the pelvic region. Basking sharks are rarely encountered until they have reached 3 m in length. The smallest free-living specimen reported is 1.65 m (Compagno 2001) but seven basking sharks measuring between 1.25 m and 1.83 m are recorded in the Atlantic observer database (Campana pers. comm. 2007).

Interspecific interactions

The presence of basking sharks on the ocean surface in areas of high zooplankton concentrations, combined with the anatomical adaptation of specialized gill rakers, suggests that they are primarily planktivores. Stomach content analyses confirm that zooplankton is the preferred prey, but these analyses are based primarily on basking sharks that were active at the surface when they were captured in commercial fisheries. Deepwater pelagic shrimps have been found in the stomach of one basking shark from Japan suggesting that mesopelagic food sources may be important too. Compagno (2001) mentions an anecdotal report of basking sharks preying upon small schooling fishes such as herring. Similarly, a gillnet fisherman from British Columbia reported catching a 7.8 m (26 ft) basking shark which when hoisted by the tail with a crane, was found to be full of 20 cm (8 inch) herring (Gisborne pers. comm. 2004a). Thus, a wider range of prey sources, aside from zooplankton, may be utilized. Basking sharks have been found to actively seek out areas of high zooplankton concentrations (Sims *et al.* 1997; Sims and Quayle 1998). Sims (1999) calculated that a minimum prey density of between 0.55 and 0.74 g·m-3 would be required for net energy gain and corroborated his estimate with field observations. This implies that basking sharks can survive and grow in conditions where prey concentrations are lower than previously thought necessary (Parker and Boesman 1954).

Behaviour

Basking sharks are known for their tendency to appear seasonally in large aggregations in particular localities where they are observed intermittently over several months before disappearing again (Darling and Keogh 1994; Compagno 2001). In British Columbia, anecdotal and newspaper accounts also indicate that several bays and small inlets were noteworthy for the regular occurrence of high densities of basking sharks. These aggregations may reflect some unknown breeding or foraging behaviour (Harvey-Clark *et al.* 1999; Sims *et al.* 2000).

Adaptability

All known or inferred life history parameters imply that basking shark populations cannot recover quickly following a reduction in abundance. They may respond to changes in the environment by shifting their distribution to more favorable areas. Aquaculture or artificial captive breeding is not a feasible option to promote recovery.

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Appendix B: Basking shark abundance and mortality in the North Pacific

INTRODUCTION

The North Pacific population of the basking shark, *Cetorhinus maximus*, is designated Endangered on the IUCN Red List of Threatened Species (Fowler 2000 in IUCN 2007), and basking sharks have been listed as Vulnerable Globally under Appendix II of CITES (2002). Canada has recently recognized that the population on its Pacific coast may have declined by 90% since the 1920s and has designated it Endangered under COSEWIC (2007). Protection has been afforded to basking sharks in US Pacific waters since 2004 when they came to be managed as a prohibited species, which makes their retention illegal (PFMC 2007).

In order to develop an understanding of abundance trends for basking sharks in the North Pacific, including waters beyond the continental shelf, we made a comprehensive examination of historical records and more recent data. Records examined were from scientific sources, newspapers, government records pertaining to the Canadian eradication program, commercial harvest and sports fishing logs, studies of international fisheries bycatch, and anecdotal reports. These records are summarized, along with their sources, in Tables B – 1 and B – 2. Canadian records are listed in detail in Tables B – 3 to B – 7, while US and other north Pacific records are listed in detail in Tables B – 8 to B 10.

CANADIAN PACIFIC ABUNDANCE AND MORTALITY

The current population of basking sharks in Canada's Pacific waters is unknown. Evidence from historical records clearly shows a wide distribution with several localized populations numbering in the hundreds or possibly thousands. At present time basking sharks appear to be no more than an infrequent visitor in Pacific waters with only six confirmed sightings since 1996, of which four are from trawl observer records (Tables B – 3 and B – 4). There is no basis for estimating the population.

Pacific fluctuations and trends

To assess basking sharks over three generations requires going back at least 66 years. From 1900 to 1970, basking sharks were regularly found in numerous locations along British Columbia's coast (Table B - 5). Throughout this period they were subject to a commercial harvest, a directed eradication program, incidental catch, and sport harpooning. Wallace and Gisborne (2006) and COSEWIC (2007) summarized all known historical records of basking sharks in Canada's Pacific waters and concludes that over 1000 sharks were likely killed between 1945-1970, which in turn can be used as a minimum historical population size (Table B – 1). There is no trend information available nor is there any basis for estimating the percent decline except that it appears to be substantial.

Scientific Record in Canada

The scientific record for the Pacific population is limited. In 1905 there is a brief mention of basking sharks in the *British Columbia Fisheries Commission* report stating that they are common in Queen Charlotte Sound during the summer months and that they are harmless and can be touched by hand. The first scientific account was by

Clemens and Wilby (1935) who describe the basking shark as "common along the British Columbia coast." Dr. W. A. Clemens in a letter to Chief Supervisor of Fisheries, J. A. Motherwell in April 1935 noted that while on a fur seal survey there were "numerous humpback whales and basking sharks" approximately 25 miles south of Pachena (southwest Vancouver Island coast). Darling and Keogh's (1994) paper is the only scientific study on basking sharks on Canada's Pacific coast.

Canadian Commercial Fishery

Most information on the commercial fishery for basking shark livers is qualitative from newspaper reports. A newspaper article from 1921 quotes the head of Consolidated Whaling Company who describes how "schools of thousands [basking sharks]" in Alberni Canal were so dense that in July "one of the coastal steamers ran into such a solid school of these big fellows that, packed tightly against the sides of the boat and around her bow, they stopped her completely" (Port Alberni News, August 31, 1921). Fisheries statistics from this era make no reference to basking shark landings, as the products of the basking sharks were likely sold and categorized as reduction products such as fish oils, fish meal or fish fertilizer.

Based on economic data and newspaper sources, it appears that the war-era commercial fishery for basking shark liver was likely limited to the years between 1941 and 1947. Newspaper articles from 1946 report that "several fishboats in the Bamfield area" were utilizing harpooning techniques in the pursuit for basking sharks (Vancouver Sun, December 3, 1946). Unfortunately all basking shark landings were lumped together and reported as "Mixed Shark" which was comprised of brown cat, blue, sleeper, and salmon sharks. Between 1941 and 1945 there was 379 t (841,600 pounds) of mixed shark liver reported. According to newspaper records, each basking shark yielded approximately 450 kg (1000 pounds) of liver. If, for example, 10% of the liver landings were from basking sharks, then approximately 80 sharks would have been processed. There is no basis to make any assumptions on the numbers of sharks killed but is likely in the low hundreds.

Fisheries Interactions and Eradication in Canada

For much of the last century, basking sharks were considered a nuisance to commercial salmon fishing operations, both gillnetting and trolling. Basking sharks appeared to favour habitats similar to those of salmon (i.e., dense zooplankton) and consequently interacted with salmon fishing fleets. Mortality was incurred from both entanglement and directed eradication aimed to reduce the nuisance factor. Reports of basking sharks in commercial groundfish trawl fisheries since 1996 suggests that bycatch of basking sharks would have occurred throughout the 70 year history of the trawl fleet.

Following are some brief descriptions taken from newspapers and other reports to assist in describing the interactions and for estimating mortality.

Rivers Inlet

A photograph taken in 1901 in Rivers Inlet is the first verified interaction of a basking shark with the salmon gillnet fleet (BC Archives 2004). In 1942, "hundreds of huge basking sharks" were reported to have caused "thousands of dollars" worth of damage to gillnets in the Rivers Inlet district (Province [Vancouver], August 14, 1942). In 1943, BC Packers responded to this loss by designing the "razor-billed shark slasher" a

specially fitted boat "with a sharp steel ram [that] cuts the sleeping monsters down as they lay on the surface" (Province [Vancouver] February 3, 1943). Only six sharks were reported in the media to have been killed by this device (Province [Vancouver], July 12, 1943), and it is unknown if the slashing device was utilized subsequent to 1943. In June of 1944 it was reported that "giant sharks [basking] are again annoying sockeye salmon fishermen at Namu" and that the sharks are "much bigger than in other years" (Daily Colonist [Victoria], June 29, 1944). In 1947, it was reported that "numbers of huge sharks" were inflicting "heavy damage" on the 100 boats fishing in Rivers Inlet (Province [Vancouver], July 2 1947). In July 1947, it was reported that "along the mainland coast...thousands of basking sharks have invaded the waters in the past week" (Daily Colonist [Victoria], July 16, 1947). Since 1948 there have been no further records of basking sharks in the Rivers Inlet area. There are several other newspaper references to this area listed in Table B - 1.

Barkley Sound

Anecdotal and newspaper reports describe locations in the Barkley Sound region with hundreds if not thousands of basking sharks. Between 1945 and 1969, and possibly earlier, basking sharks were a well known nuisance to Barkley Sound gillnetters (Table B - 6). Despite annual calls by fishermen for an eradication program between the years of 1948-1954, it was not until 1955 that the Federal Fisheries department actively engaged in an eradication program. From 1955-1969, 413 sharks were killed by a large blade mounted on the bow of a fisheries patrol vessel (Table B - 6). Prior to the blade method of eradication, shooting and harpooning by patrol vessels was also tried. Concurrent to the blade method, other patrol vessels at the time were under directive to opportunistically ram basking sharks which may account for an additional 200-300 kills (Fletcher 2004 in Wallace and Gisborne 2006).

Entanglement was likely the largest source of mortality, but cannot be quantified. Once a basking shark became entangled in gillnets, sharks either drowned or were killed by fishermen in an attempt to salvage their nets. One Barkley Sound fishermen recounted killing seven or eight to save his net. It is estimated that there were approximately 150 gillnetters in Barkley Sound during this period and therefore many mortalities would have gone unrecorded (Peterson 1999). There were also reports of entanglement in trolling gear (Table B – 6). It is suspected that anywhere between 400 and 1500 sharks may have been killed from entanglement in Rivers Inlet and Barkley Sound from 1942-1969 (COSEWIC 2007).

Canadian Sport Kills

It is not possible to estimate the number of basking sharks killed for sport in the 1940s through to the mid-1960s as the only written records are from newspaper stories (Table B – 7). In the 1940s, the sport of harpooning basking sharks had acquired enough interest that the Canadian Pacific Railway promoted fishing for BC basking sharks in publicity releases (Daily Colonist [Victoria], September 27, 1953). One newspaper article describes a person harpooning ten and landing five in a single day around the waters off Texada Island in June (Province [Vancouver], June 7 1947). Sport kills for basking sharks, which includes all forms of 'recreational' killing and harassment leading to death was likely in the multiple hundreds (50-400).

Estimated Total Mortality in Canada

There is great uncertainty associated with trying to interpret and quantify historical information. All evidence suggests substantial levels of lethal interactions. For the purpose of this report, it is estimated that the total number of sharks killed by eradication is 413, other patrol/eradication methods (200-300), entanglement (400-1500), and sport kills (50-400). This results in a range of kills between 1000-2600. This number in turn can be used as a minimum historical population estimate.

Clayoquot Sound

Darling and Keogh (1994) provide a thorough report of basking shark behaviour, abundance and distribution in Clayoquot Sound using observations from 1973-1992. Aerial sightings and other anecdotal reports indicate that basking sharks were in the Sound throughout the 20 year period investigated. A single summer of photographic identification work undertaken in 1992 resulted in 27 individuals being photo-identified. Many of the sharks had wounds which may have been from boat propellers, a theory which was supported by observations of the sharks seemingly being attracted to boat propellers. The following summer resulted in a few sporadic sightings (not reported) and since 1994 there have been no confirmed sightings from Clayoquot Sound. Their disappearance coincides with the rapid development of salmon aquaculture in the region but there is no evidence to link these two events (Darling 2003 in Wallace and Gisborne 2006). It is likely that their sudden disappearance is caused by unknown natural phenomena. Basking sharks have been documented to exhibit periodic absences in the timescales of decades. Jordan (1887), who wrote extensively on whaling, noted that in Monterey Bay the basking shark is sometimes not seen for 20 years.

RECENT US PACIFIC ABUNDANCE AND MORTALITY (1980 – 2007)

Recent sightings and observations from California (1990 – 2007)

Since 1994, basking shark sightings have been extremely rare in US waters along the Pacific coast from California to Washington and including Alaska, even in areas in south-central California where large aggregations of basking sharks were observed historically. However, no record could be found of any more than 2 to 3 basking sharks being observed at one time in the coastal Pacific waters since 1993. Sightings of basking sharks by fisheries observers and surveyors, whale watchers, and tagging programs, and records of occurrence as bycatch in a commercial fishery are shown in Table B – 8. From 1990 to 1993, basking sharks were sometimes seen in Monterey Bay and most of the 146 basking sharks tagged in various programs were tagged during those years (SWFSC 2006; Ugoretz 1999; Van Sommeran, pers. comm. 2007).

Aerial surveys

Despite the fact aerial surveys have been conducted for harbor porpoise along thousands of kilometers of the central and northern California coastline since 1991,, only seven basking sharks have been observed during that time (Table B – 9) (Forney, pers. comm. 2007, Carretta pers. comm. 2007). Aerial surveys occurred in alternate years from 1991 to 1999, and in 2002 from August 15 through November 15, and typically covered thousands of kilometers from Point Conception to the Oregon border in mostly inshore transects, with a few offshore transects beyond the 200 m isobath (Benson *et al.* 2007; Carretta and Forney 2004). The sharks were reported from six aerial surveys that

occurred during 1993, 1999 and 2002, from August to October in the Morro Bay area from Point Conception to Point Sur, the Big Sur coastline). No basking sharks were seen during the surveys conducted in 1991, 1995, and 1997. A further four basking sharks were sighted in Monterey Bay during 2000-2007 on fine-scale leatherback turtle surveys conducted in several nearshore areas off the central California coast (Benson *et al.* 2007; Peterson *et al.* 2006). Three of the sightings took place during September of 2002, and one in September of 2003, but none during 2004, 2005 or 2006. Basking shark sightings were considered rare, with the ones made in 2002/2003 associated with high krill production that was much reduced after 2004 (Forney, pers. comm. 2007).

Aerial fish spotters have been employed in the coastal pelagics purse seine fisheries off the coast of California for many years, although recent aerial surveys have focused mainly on offshore tuna in waters that are further south than traditional basking shark territory, primarily off Mexico (Squire 1990). Since 2003, a directed aerial survey has operated that has attempted to retain some of the coastal pelagic data, generally operating in winter/spring off the southern California Bight, and although pilots confirm that they do not systematically record basking shark sightings, they did report a single basking shark in 2004 (Dotson pers. comm. 2007). Anecdotal evidence from a long time pilot employed in the coastal pelagic fisheries, who also works with swordfish harpoon boats and bonito fishermen in traditional basking shark waters, suggests that the large aggregations usually seen within 3-5 miles of the shoreline off California up to a decade ago are no longer seen (Dotson, pers. comm. 2007).

Tagging programs

Since 1990 a total of 146 basking sharks have been tagged with conventional tags (i.e., those that can be identified visually without the use of special detection equipment) in three programs that have operated on the Pacific coast of the US. A total of 81 basking sharks were tagged and released in the Monterey Bay area by the Pelagic Shark Research Foundation since 1990, and of these, 78 were tagged in 1990 and 1991 (Van Sommeran pers. comm. 2007). A total of 58 basking sharks were tagged and released from Monterey Bay to Cabo San Lucas by the California Department of Fish and Game Cooperative Shark Tagging Program; most sharks were tagged in 1991, with a few also tagged in 1990, 1993, and in a follow up program in 2000 (Martarano pers. comm. 2007; Ugoretz 1999). A total of seven basking sharks were tagged and released in the Billfish Tagging Program operated by the Southwest Fisheries Science Center, NOAA Fisheries Service in 1991 (Rasmussen pers. comm. 2007; SWFSC 2006). None of the tagged basking sharks have been recovered to date (Martarano, pers. comm. 2007; SWFSC 2006; Ugoretz 1999; Van Sommeran pers. comm. 2007). This low recovery rate has been attributed to the fact that, although the sharks are easy to tag when they are found slowly feeding at the surface, they are rarely recaptured, possibly due to low abundance but also because basking sharks are not often caught incidentally on most gear types, no directed fishery exists, and since 2000 there has been a prohibition on capture in California (Kohler and Turner 2001).

Sean Van Sommeran, president of PSRF, provided the following details of the basking shark taggings and sightings: 38 sharks were tagged in 1990; 40 more in 1991; and six of the sharks tagged in 1990 were resighted in 1991. In 1993, many sharks were seen one day when three sharks were tagged, but when researchers returned a few days later they were gone. In 2000, only two or three sharks were seen and only one was tagged, while in 2002 only a single basking shark was seen and none were tagged. All sharks were tagged in Monterey Bay where none have been seen since

2002, but two or three are reported to the south off Big Sur every year (Van Sommeran pers. comm. 2007).

Incidental sightings from whale watching networks

The Monterey Bay Whale Watch, a commercial whale watching company and research group has maintained a record of monthly sightings of marine mammals as well as leatherback turtles and basking sharks on the internet since September 1997at http://www.montereybaywhalewatch.com/sighting.htm (Accessed Sept. 25, 2007). The only record of basking shark sightings occurred off Moss Bay in 2000, with two sighted on June 28, one on June 29 and one on July 01.

An exceptional visit by a large group of basking sharks to Monterey Bay in the winter of 1990/1991 was mentioned in "Soundings," the California American Cetacean Society, California Chapter's newsletter (Black 1991). Small groups of basking sharks were first seen off Santa Cruz in November of 1990 and then on February 12th 1991, 70 to 100 were observed in Monterey Bay just south of Moss Landing. During November and December of 1990, Sean Van Sommeran of Pelagic Shark Research Foundation tagged 15 of the sharks with yellow tags from California Fish and Game and 2-3 of these were seen again on February 16th 1991 in a group of 12 to 15. By February 26th some sharks were still in the bay but the bulk of the aggregation had disappeared. A local skipper (Richard Ternullo of the Monterey Bay Whale Watch) who had been working in the bay regularly for a many years is quoted as saying that the last time a school of basking sharks was seen in the area was in 1976 inside Carmel Bay.

Other observations

Baduini (1995) combined personal observations with publicly gathered sighting reports of basking sharks in research comparing basking shark abundance with zooplankton abundance and composition in Monterey Bay and the Santa Barbara Channel Islands in California, Clayoquot Sound in British Columbia, and the Gulf of Maine from 1989 to 1992. The largest group of sharks reported was a sighting of 30 off the kelp beds at Big Creek, Big Sur in August of 1992. In February 1991, four to five sharks were observed feeding on at least five occasions in Monterey Bay, while in December 1991 a group of 15 to 20 were observed repeatedly feeding in the northern bay area. Fifteen to 20 sharks were also observed off Long Marine Lab in Santa Cruz in November and December of 1991. A group of 20 sharks was reported feeding off Santa Barbara Channel Island in April 1989.

Recent sightings and observations from Oregon, Washington, and Alaska (1980 – 2007)

Basking sharks are included in the list of seven shark species known or suspected to occur in the Gulf of Alaska groundfish stock assessment reports, but its inclusion on the list was due to a single animal being observed during an Alaska Fisheries Science Center survey (Gaichas *et. al.* 1999). Only one basking shark has been identified by an observer in any federally managed fishery in Alaska since the late 1980s, and no records were found of basking sharks in state managed fisheries besides a single anecdotal report of a local fishermen catching a basking shark in 1980 or 1981 near Prince of Wales Island (Courtenay pers. comm. 2007; Gaichas pers. comm. 2007; Hulbert pers. comm. 2007; Rigby pers. comm. 2007).

Unlike the harbor porpoise surveys conducted along the coast of California, surveys for porpoise in the coastal waters of Oregon and Washington have not recorded any basking shark observations (Laake, pers. comm. 2007). The only account, unconfirmed, of a basking shark sighting in Oregon occurred in 1994 in Lincoln County, Oregon and was reported in the Sandpiper (2007), a publication of the Yaquina Birders and Naturalists. Likewise, a single basking shark was photographed near McNeil in Puget Sound, Washington in September of 2007 and reported to the Washington Department of Fish and Wildlife (Evenson, pers. comm. 2007). J. Rupp of the Point Defiance Zoo and Aquarium hears of one or two basking shark sightings a year, but the last authenticated report from Puget Sound was in 1989 with the incidental capture of a 25 foot male (Rupp pers. comm. 2007).

Recent Fisheries Interactions in the United States (1980 – 2007)

Protective legislation

Basking sharks are currently managed by the Pacific Fisheries Management Council (PFMC) as a Prohibited Species under the Fishery Management Plan (FMP) for US West Coast fisheries for Highly Migratory Species (HMS) which was adopted in June of 2007 (PFMC 2007), but retention of basking sharks has been prohibited along the US west coast since 2004, as specified in an earlier version of the Federal Management Plan. A prohibited species must be released immediately if caught, unless other provisions for its disposition are established, including scientific study. For basking sharks, retention is prohibited except for sale or donation of incidentally caught specimens to recognized scientific and education organizations. Retention was previously banned in California waters by the California Department of Fish and Game in 2000, but not as a result of any known decline in shark numbers (Bizzarro pers. comm. 2007).

The landing of incidentally caught sharks has received some further disincentive from enactment in 2002 of the Shark Finning Prohibition Act of 2000 which prohibits any person subject to US jurisdiction from engaging in shark finning, possessing shark fins aboard a US fishing vessel without the corresponding carcass, or landing shark fins without a corresponding carcass (NMFS 2005).

California/Oregon swordfish/shark drift gill net fishery

In the California/Oregon drift gill net (DGN) fishery for swordfish and sharks, logbooks are collected and analysed, and since 1980, with the exception of a few years, either the California Department of Fish and Game or NMFS Southwest Region has fielded an observer program to record catch and bycatch. A review of all 7,721 DGN sets that have been monitored by observers for the years 1990–2005 in all areas, demonstrates very low interaction rates with prohibited shark species (PFMC *et al.* 2006). There have been a total of two basking sharks captured by DGN gear during that time span. Of the two basking sharks reported by observers, the one caught in 1993/1994 was released dead and the one caught in 2002/2003 was released alive (Observer Program data summaries are available online at http://swr.nmfs.noaa.gov/psd/codgftac.htm). On average, 20% of the sets were observed, 13% in the 1993/1994 season and 22% in 2002/2003. Fishing effort declined after the mid 1980s, with 11,000 sets (equivalent to days fished) made in the 1986/1987 season, only 2,401 sets in 1999/2000 and just 1022 sets in the 2004/2005 season, partly due to seasonal area closures. The two observed catches on record can be

extrapolated to 7.7 sharks caught in the 1993/1994 season and 4.5 sharks in the 2002/2003 season. These numbers are not high compared to other shark species but little is known about the population size at the time and on the recovery rate of caught and released basking sharks. Observer records for 1980-1991 also noted the occurrence of basking sharks, but their numbers were not identified in the report written by Hanan *et al.* (1993) for the California Department of Fish and Game.

California halibut/angel shark set gill net and swordfish/thresher shark drift gill net fisheries

The California halibut/angel shark set gill net and swordfish/thresher shark drift gill net fisheries are both classified as Category I fisheries under the U.S. Marine Mammal Protection Act (MMPA), meaning that 'levels of incidental serious injury and mortality of a given marine mammal stock are greater than or equal to 50% of the Potential Biological Removal (PBR) level for that stock' (SWFSC 2007). Category I fisheries are subject to monitoring by observer programs, which provide data on incidental marine mammal bycatch. NMFS observer programs for the halibut/angel shark set gill net fishery were initiated in 1990 and operated until 1994, and were reinstated in 1999 (Carretta *et al.* 2004). Restrictions on fishing distance from the shoreline in 1994 reduced the fishing effort by almost 50% (Julian and Beeson 1998). Logbooks from the California small mesh set gill net fishery for halibut and angel sharks report the capture of two basking sharks between 2001 and 2004, when 76 vessels fished 4782 days (NMFS-SWR *et al.* 2007). No basking sharks were reported in logbooks for 2005/2006.

Hawaii surface set longline fishery

Observer records for the Hawaii-based surface set longline fishery indicate that a basking shark was caught and released dead in December of 2003 (PFMC *et al.* 2006). This was the only record of basking shark in the observer records from 1994 to 2007 held by the NMFS Pacific Island Regional Office (PIRO 2007).

"Partyboat" recreational fishery

Historical logbook databases revealed only five basking sharks reportedly kept in the commercial passenger fishing vessel ("partyboat") fishery between 1957 and 1997 (Hill and Schneider 1999).

California commercial landings records

A total of six records were found of basking shark landings in the California commercial fish landing records since 1990 at various ports in California, with one as recent as 2004 (CDFG 2006). The weight of landings, ranging from 15 to 888 pounds, are far too low for whole basking shark, and while they may represent body sections it is more likely that the landing forms were filled out in error, particularly since retention of basking sharks has been illegal in California since 2000.

West coast groundfish commercial and research trawl fisheries

Basking sharks have not been observed in US West Coast Groundfish fisheries (Cusick pers. comm. 2007) and have not been caught in the west coast groundfish trawl surveys (Keller pers. comm. 2007). This is somewhat surprising when compared to the US Atlantic coast fisheries for squid, Atlantic mackerel, and butterfish (SMB) alone, where the Northeast Fisheries Science (NEFSC) Observer program database records 17

basking sharks caught but not retained, between 1995-2000, primarily in the *Loligo* fishery (MAFMC and NMFS 2007).

US state fishery agency databases

The Pacific Fisheries Information Network (PacFIN) is a joint Federal and State data collection and information management project (PacFIN 2007). Washington, Oregon, and California fishery agencies data sources supply species-composition and catch-by-area proportions developed from their port sampling and trawl logbook data systems. The NMFS/AFSC inputs weekly aggregates developed from their tow-by-tow observer database and data for the Alaska groundfish fishery are provided by the Alaska Department of Fish and Game (ADFG) and the NMFS/AKR in the form of monthly and weekly aggregates. Fisheries and Oceans Canada also makes a contribution to this data system. Best estimates of catch for each groundfish species by month, area, and gear-type are developed from these source data. Unfortunately, although PacFIN shows basking shark in its agency description of species and assigns it a category number of 156, it reports it as "Other Shark, OSRL C".

Basking sharks are included in the list of 7 recognized species of sharks in Alaskan waters but this was based on a single shark being observed in a survey (Gaichas pers. comm. 2007; Gaichas *et al.* 1999). There is also only one record of a basking shark observed in a federally managed fishery in Alaskan waters since the 1980s and although basking sharks are not always categorized on the species lists, onboard observers usually identified sharks because they were easy to recognize (Gaichas pers. comm. 2007). The rarity of basking sharks in waters of Alaska is also reflected in the lack of a code for them in the Alaska Department of Fish and Game Commercial Fisheries species list for the fish ticket database of the Commercial Fisheries Division (Hulbert pers. comm. 2007).

HISTORIC US PACIFIC ABUNDANCE AND MORTALITY (1800S – 1985)

Historic sightings and observations from California (1930 – 1985)

In 1935, Walford wrote that basking sharks occurred during the winter months between November and February, mostly in Monterey and San Simeon Bays, sometimes in schools of 20 or 30 individuals. Chute (1930 in Squire 1967) reported that fishermen in Monterey Bay spoke of seeing aggregations of up to 500 sharks.

Aerial fish spotters were employed by basking shark fishery in Monterey Bay and San Louis Obispo/Morro Bay from 1948 to 1950 (Squire 1967). More than 2000 sharks were seen on a single flight over the Monterey Bay area in early October 1948 and from 100 to 500 animals were observed on 10 other occasions. The observation of 2000 sharks in one overflight is the basis of the minimum population size estimate of 2000 individuals in central California at that time. The spotters flew a total of 456 flights from February 1948 to October 1950, with one or more basking sharks observed on 51.5% of the flights and an overall average of 19.2 sharks observed per flight (on the flights on which they were observed). From the middle of February 1950 through until the end of the flights in October 1950, no more than 10 basking sharks were ever seen on a single flight, likely due to diminishing numbers of basking sharks in the area (CITES 2002),

Aerial fish spotters were employed in the coastal pelagics purse seine fisheries year round off the coast of California from 1962 to 1985 (Squire 1990). These spotters provided reliable and quantifiable observations of basking sharks even though the number of surveys in traditional basking shark territory was much reduced in the later years (Squire 1990). During 1962 to 1964, from 50 to 60 sharks were seen per block area flight (i.e. 10 minutes longitude x 10 mintues latitude or 8 x 10 nautical miles at the latitude of California) in blocks where they were observed, and in 1966 almost 140 sharks were seen per block area flight (Squire 1990). After 1967 the number of basking sharks seen per block area flight was never more than 10, except for in 1981 when 30 basking sharks were seen per block area flight. The greatest abundance of basking sharks were observed in the block area that encompasses Morro Bay, where an average of 98.8 basking sharks were observed on 66 flights on which they were observed, whereas basking sharks were seen on 19 occasions in Monterey Bay with an average of 42 sharks per sighting. Although basking sharks were never seen in great numbers south of Point Conception, 2 to 3 sharks were observed on 64 occasions in a block area off the coast of Santa Barbara. The overall decrease in abundance observed after 1970 was considered a fluctuation influenced by increasing sea temperature changes and El Niño perturbations (Squire 1990).

Historic Fisheries Interactions in California (1800s to 1950s)

Since the late 1800s, basking sharks on the central coast of California from Monterey Bay to Morro Bay had been taken incidentally when they became caught in fishermen's nets or were taken in the whale fishery. Two were reported in the catch of the Monterey Whaling Company in the 1879 - 1880 season along with 14 whales (Jordan 1887). Even then it was noted that the basking sharks were rare and were sometimes not seen in Monterey Bay for 20 years.

In the early 1920s basking sharks arrived in unaccountably large numbers and became a nuisance by becoming entangled in and damaging fishing nets, inspiring local entrepreneurs to begin a sport fishery by enticing tourists on harpoon hunting trips (Thomas 2004). A directed commercial fishery for basking sharks began as early as 1924, when an average of 25 sharks were landed each season (September to May), with sharks provided to the local reduction plant. The fishery continued until 1938, with a maximum of 100 sharks landed in a single year (Phillips, 1948). The directed fishery came to an end in 1938 when a decline in basking shark numbers coincided with the local reduction plant burning down, while local market interests shifted to soupfin sharks.

The commercial fishery for basking sharks underwent a brief resurgence in 1946, with the development of new uses for shark liver oil. The primary market for basking shark oil products was in a leather tanning process, since the oil was not found to be a good source of vitamin A or D, and did not work well in soap or paint manufacturing (Phillips 1948; Roedel and Ripley 1950). About 300 basking sharks were landed in the first September to May season of the new fishery (Phillips 1948, Thomas 2004). The fishery came to comprise 12 vessels operating in Monterey Bay and six in the San Luis Obispo Bay area, with some aerial support by spotting planes (Phillips 1948). A 1949 report of the shark and ray fisheries for the California Department of Fish and Game (Roedel and Ripley 1950) stated that about 200, 13-33 feet long basking sharks were taken in the Monterey Bay harpoon fishery in 1948, and 100 were landed at Pismo Beach in 1947. Although a few were also landed at Santa Barbara, the industry was limited by available facilities for landing and processing facilities. It has been estimated that 200 basking sharks were taken in each year from 1948 to 1950, and that effort

declined drastically after the spring of 1950, due to low prices for oil and diminishing numbers of basking sharks, with the fishery ending by 1952 (Thomas 2004; CITES 2002; Roedel and Ripley 1950).

SEASONALITY OF ABUNDANCE IN BC AND US WATERS

Basking sharks in British Columbia and California may belong to a single seasonally migrating population. This is based on convincing data showing that the seasonal disappearance of basking sharks from California waters between May and July (Squire 1967, 1990) coincides with the appearance of basking sharks in relative abundance in British Columbia waters (Darling and Keogh 1994).

Extensive aerial surveys were conducted in 1948 – 1950 in support of the basking shark fishery in Monterey Bay, California (Squire 1967), and in 1961 – 1985 in support of the coastal pelagics purse seine fisheries off the coast of California, and south to the Santa Barbara Channel Islands (Squire 1990). Both sets of observations show the peak of abundance to occur in October and February/March, while the lowest abundances occurred in June through August, despite these months being the months of highest phytoplankton activity (Squire 1990). The seasonality of basking shark abundance off California has been noted in many earlier accounts. Roedel and Ripley (1950) reported that basking sharks were most abundant from September to April off Pismo Beach and Morro Bay. Phillips (1948) reported that from 1946 to 1950, basking sharks in San Luis Obispo, Morro, and Monterey Bays were generally encountered in the fall within a few miles of shore and sometimes right in the surf. Walford (1935) stated that schools of 20 to 30 animals were sometimes seen in Monterey and San Simeon Bays in the winter months between November and February. Another early account reported that fisherman said basking sharks occurred year round in Monterey Bay but only appeared close to shore during fall and winter (Chute 1930 in Squire 1967).

The seasonal abundance of basking sharks in Clayoquot Sound, British Columbia, was described by Darling and Keogh (1994) who looked at records of basking shark sightings in the area from 1973 to 1992. All sightings in Clayoquot Sound occurred in March – October, with the most sightings occurring in May – September.

INTERNATIONAL FISHERIES

Coastal Japan

A traditional basking shark harpoon fishery operated from the 1700s until 1980 in the nearshore waters of Japan off Nakiri (CITES 2002). This is an area to which the sharks migrate from March to May and where they are thought to mate (CITES 2002). The fishery became more intensive in 1967 when the price for oil increased. In 1967 - 1978 1200 sharks were harpooned, with an average of 100 sharks landed per year. Catches declined rapidly from about 150 in 1975 to 20 in 1976, to just 6 in 1978. The fishery ended in the 1980s due to declining shark oil prices and numbers of sharks. Two or fewer basking sharks were sighted each year in the 1990s in the migration area off Nakiri (CITES 2002).

High Seas Driftnet fisheries

Japan, Korea, and Taiwan were the primary participants in the high seas driftnet fisheries (i.e., squid, salmon and large mesh net for tuna) of the north Pacific that operated in the 1980s. These fisheries were responsible for catching considerable numbers of sharks and rays as bycatch until they were stopped at the end of 1992 as a result of international agreements (Table B – 10) Bonfil (1994) extrapolated shark catches for 1990 from observer records published in reports of the International North Pacific Fisheries Commission (INPFC). A total of 54 basking sharks were estimated to have been caught as bycatch in the high seas driftnet fisheries, with 22 caught in the flying squid fishery, while 32 were caught in the Pacific large mesh drift net fishery that targeted tunas and billfishes. Although 54 is small compared to the numbers of other species of sharks recorded as bycatch, the fact that basking sharks were caught in a high seas fishery at all is surprising since it has been considered a coastal species that remains on or near the continental shelf areas.

By international agreement, drift gill nets have not legally fished in the North Pacific since 1992. However, illegal drift net fishing continues, as was substantiated in September 2007 when a Canada-US aerial patrol identified 10 boats suspected of drift net fishing illegally in the international waters of the North Pacific (Anonymous 2007).

Tuna fisheries in the tropical Pacific

There are no basking sharks recorded as bycatch from the Japanese tuna longline fishery in the years that it has operated outside the EEZ of tropical Pacific Asian nations, or for the tropical tuna purse seine fishery, but it is unknown whether this is due to poor reporting, or to the fisheries being propagated in areas where basking sharks have been uncommon.

Nineteen basking sharks were caught in the Japanese tuna longline fishery in the North Pacific between 1967 and 1970 (Nakano 1999). Prior to 1970, the fishery took place in the Exclusive Economic Zone (EEZ) of nations in the tropical Pacific Ocean, and hence coastal species were common in the bycatch (Nakano 1999). By the late 1970s, Japanese fishing fleets were excluded from the EEZ of most other nations, and coastal species therefore became more rare in the bycatch (Nakano 1999). Research into Japanese catches made from 1992 to 1994 does not report any basking sharks (Nakano 1999).

The Inter-American Tropical Tuna Commission (IATTC) provided observer coverage of the tuna purse seine fishery between 1993 and 2004; however, no basking sharks were reported (Román-Verdesoto and Orozco-Zöller 2005). Of all sets laid during the 12 years of IATTC observer coverage, 23% held shark bycatch, mostly in numbers low enough to be counted, with only 1.4 - 2.3% (depending on gear type) of the sets containing shark bycatch estimated in metric tonnes. The IATTC species code list includes basking sharks (code SKX), along with 13 other species of sharks; however, no other mention of basking sharks was found in any of the IATTC literature. Even though the boundary of the IATTC mandate extents north into the waters off of British Columbia, the actual area fished rarely extends north of 30 degrees of latitude, which is further south than is usual for basking sharks along coastal North America (IATTC 2007).

Conclusions

Canada

There is little question that basking sharks once frequented British Columbia's coast in numbers and distribution much larger than found today. For most of the historical record, basking sharks were a common part of the flora and fauna regularly encountered by mariners. They were described as *plentiful* in the earliest descriptions (Green 1891). The disappearance of local populations coincides with known excessive human caused mortality, which is consistent with experiences from other regions in the world. The small Clayoquot Sound population was the last known aggregation in British Columbia. Overall, it appears that the population coastwide has declined from multiple thousands to a virtual disappearance.

United States

The central coast of California was the only area on the entire Pacific coast of North America, other than some inlets in British Columbia, where basking sharks are recorded to have gathered in large numbers. When they appeared it was usually during fall and winter in Monterey Bay and the San Luis Opisbo Bay/Morro Bay area. Altogether, the various records of basking shark sightings, bycatch, and directed catch give a clear indication of a dramatic decline in basking shark abundance in US Pacific waters since the early 1950's and illustrate how rare a sighting of a basking shark has become since the early 1990s. The recording of more than 2000 sharks during one day of aerial spotting in Monterey Bay in 1948 has been used as a minimum estimate of the population. While the opportunity to make this record may have been biased by the fact that it was made by aerial spotters assisting a directed fishery for basking sharks, more recent reports of an aerial fish spotter of pelagic species along the coast of California from 1962 to 1985 did not record such large aggregations and noted a decline after the early 1970s. Since 1990, regular surveillance of the waters of the central coast for harbor porpoise and leatherback turtles, as well as the activities several shark tagging programs and whale watching companies in the Monterey Bay area, have provided evidence that a further decline in numbers has occurred.

The greatest human-caused mortality of basking sharks in US Pacific waters occurred during directed fisheries that operated from about 1924 to 1938 and from 1946 to 1952 around the Monterey Bay and San Luis Opisbo Bay/Morro Bay areas of California. Outside of these years, the number of sharks taken opportunistically by harpoon is not recorded, but incidental catch in drift and set gill net fisheries has been reported by observer programs since 1990. Although the observed bycatch numbers have not been high, they may still constitute a level of mortality that the population cannot tolerate. Basking sharks have received protection against retention in the state of California since 2000 and along the entire US west coast since 2004, but the survival rate of caught and released sharks is unknown.

Overall, it is clear that the population of basking sharks in US Pacific waters has undergone a decline of at least the same magnitude as that seen off the coast of British Columbia. Therefore it is unlikely that we can expect any rescue effect for basking sharks in BC from US Pacific waters.

International Fisheries

Just as for the Pacific coast of North America, the Pacific coastal regions of Asia likely once supported sizable populations of basking sharks, which have undergone rapid declines in recent years and may have virtually disappeared. At one time, a population of basking sharks is thought to have migrated to coastal waters off Nikiri Japan in order to mate. This population supported a traditional harpoon fishery for several centuries, but underwent a rapid decline when fishing intensified in the 1960s. Between 1967 and 1978, 1200 sharks were harpooned, with an average of 100 sharks landed per year; however, by the 1990s, two or fewer basking sharks were sighted each year.

High seas drift net fisheries were responsible for catching basking sharks in the North Pacific until they were banned in 1992, and although the numbers or basking sharks were low compared to other shark species, the vulnerability of basking sharks to exploitation is comparatively high, and basking sharks may continue to be susceptible to illegal high seas driftnet fishing.

It is not known if basking sharks caught elsewhere in the North Pacific are part of the same population as those on the Pacific coast of North America. If these sharks are to create a rescue effect for basking sharks in coastal BC, then these animals also need protection. Canada and the United States already contribute to enforcement of the prohibition on high seas drift net fishing in the North Pacific, and thereby contribute to reducing the level of mortality of basking sharks and other bycatch and discard animals. Unfortunately, the recent interception of boats in the North Pacific that were possibly drift net fishing demonstrates that the international community cannot relax its vigilance and might consider increasing it (Anonymous 2007).

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Table B - 1. Summary of reported human encounters with basking sharks in the Pacific waters of Canada.

Year	# of basking sharks	Encounters		Location	Source
		Live	Dead		
2005	1	Sight		Queen Charlotte Islands	Burke 2005
	1	Sight		Queen Charlotte Islands, southern	COS 2007; W & G 2006
2004	1		Bycatch*	Rennell Sound	COS 2007; W & G 2006
2002		Sight		30 mi. SW of Rose Spit	COS 2007; W & G 2006
2000	2		Bycatch	51.88, 130.54; 51.70, 130.72	COS 2007; W & G 2006
1999		Sight		49 39 50N, 124 50.8W	COS 2007; W & G 2006
1996	1		Bycatch	51.86, 130.52	COS 2007; W & G 2006
1993	2	Sight		Clayoquot Sound	Baduini 1995
1992	1 (x84)	Survey		Clayoquot Sound (84 sightings; usually 1 shark, sometimes 2 per sighting; 27 sharks identified)	Darling and Keogh 1994
	1 (x6)	Sight		Clayoquot Sound (6 sightings, number of sharks not given)	Darling and Keogh 1994
	1		Bycatch	Clayoquot Sound (Millar Channel)	Darling and Keogh 1994
	1		Bycatch	Clayoquot Sound (Megin River Estuary, Shelter Inlet)	Darling and Keogh 1994
1991	1 (x1)	Sight		Clayoquot Sound (1 sighting, number of sharks not given)	Darling and Keogh 1994
		Sight		Clayoquot Sound (Sidney Inlet)	Darling and Keogh 1994
		Sight		Clayoquot Sound (Sidney Inlet)	Darling and Keogh 1994
		Sight		Clayoquot Sound (Millar Channel)	Darling and Keogh 1994
1990	1 (x3)	Sight		Clayoquot Sound (3 sightings, number of sharks not given)	Darling and Keogh 1994
1989	1 (x3)	Sight		Clayoquot Sound (3 sightings, number of sharks not given)	Darling and Keogh 1994
1988	1 (x6)	Sight		Clayoquot Sound (6 sightings, number of sharks not given)	Darling and Keogh 1994
		Sight		Clayoquot Sound (Sidney Inlet estuary)	Darling and Keogh 1994
		Sight		Clayoquot Sound (Off Hisnit)	Darling and Keogh 1994
	1		Bycatch	Clayoquot Sound (Sydney Inlet)	Darling and Keogh 1994
1987	1 (x5)	Sight		Clayoquot Sound (5 sightings, number of sharks not given)	Darling and Keogh 1994
1986	1 (x6)	Sight		Clayoquot Sound (6 sightings, number of sharks not given)	Darling and Keogh 1994
	1		Dead	Clayoquot Sound (Megin)	Darling and Keogh 1994

Table B – 1. (Continued.)

Year	# of basking sharks	Encounters		Location	Source
		Live	Dead		
1984		Sight		Barkley Sound (Trevor Channel)	COS 2007; W & G 2006
1982		Sight		Barkley Sound (Trevor Channel)	COS 2007; W & G 2006
1979		Sight		Barkley Sound (Trevor Channel)	COS 2007; W & G 2006
1974	1		Killed	Barkley Sound (Sarita)	COS 2007; W & G 2006
~1974	1		Dead	Clayoquot Sound (Ahouset)	Darling and Keogh 1994
1973-85	1 (x21)	Sight		Clayoquot Sound (21 sightings, number of sharks not given)	Darling and Keogh 1994
1973		Sight		Barkley Sound (Bamfield Inlet)	COS 2007; W & G 2006
1969	6	Sight		Barkley Sound/Alberni Inlet	COS 2007; W & G 2006
	some		Bycatch	Barkley Sound	COS 2007; W & G 2006
1968	8		Killed	Barkley Sound (DFO patrol vessel with blade)	COS 2007; W & G 2006
	some		Bycatch	Barkley Sound	COS 2007; W & G 2006
1967	1	Sight		Barkley Sound (Whistle Buoy)	COS 2007; W & G 2006
	3		Bycatch	Barkley Sound	COS 2007; W & G 2006
	21		Killed	Barkley Sound (DFO patrol vessel with blade)	COS 2007; W & G 2006
1966	0	Sight		Barkley Sound/Alberni Inlet	COS 2007; W & G 2006
1965	7	Sight		Barkley Sound (Trevor Channel)	COS 2007; W & G 2006
	1	Sight		Barkley Sound (Sarita Bay)	COS 2007; W & G 2006
	8		Killed	Barkley Sound (DFO patrol vessel with blade)	COS 2007; W & G 2006
1964	"very numerous"	Sight		Barkley Sound	COS 2007; W & G 2006
1963	7	Sight		Barkley Sound	COS 2007; W & G 2006
	1	Sight		Barkley Sound (Bamfield-Sarita)	COS 2007; W & G 2006
	1	Sight		Barkley Sound (Sandford Island)	COS 2007; W & G 2006
	1	Sight		Barkley Sound (Kelp Bay)	COS 2007; W & G 2006
	1	Sight		Barkley Sound (San Mateo Bay)	COS 2007; W & G 2006
	1	Sight		Barkley Sound (San Mateo Bay)	COS 2007; W & G 2006
1963	37		Killed	Barkley Sound (DFO patrol vessel with blade)	COS 2007; W & G 2006
1962	20		Killed	Barkley Sound (DFO patrol vessel with blade)	COS 2007; W & G 2006
1961	"very numerous"	Sight	Bycatch	Barkley Sound	COS 2007; W & G 2006
	32		Killed	Barkley Sound (DFO patrol vessel with blade)	COS 2007; W & G 2006
~1961	100	Sight		Barkley Sound (Effingham Inlet)	COS 2007; W & G 2006

Table B – 1. (Continued.)

Year	# of basking sharks	Encounters		Location	Source
		Live	Dead		
1960	"very numerous"	Sight	Bycatch	Barkley Sound	COS 2007; W & G 2006
	11		Killed	Barkley Sound (DFO patrol vessel with blade)	COS 2007; W & G 2006
1959	1	Sight		Esquimalt Harbour	COS 2007; W & G 2006
	1	Sight*		Saanich Inlet (Cole Bay)	COS 2007; W & G 2006
	"large numbers"	Sight	Bycatch	Barkley Sound	COS 2007; W & G 2006
	47		Killed	Barkley Sound (DFO patrol vessel with blade)	COS 2007; W & G 2006
1958	1		Bycatch	Bowen Island	COS 2007; W & G 2006
	1		Bycatch	Bowen Island	COS 2007; W & G 2006
	1	Sight*		Oak Bay	COS 2007; W & G 2006
	52		Killed	Barkley Sound (DFO patrol vessel with blade)	COS 2007; W & G 2006
	"large numbers"	Sight	Bycatch	Barkley Sound	COS 2007; W & G 2006
1957	1	Sight		Saanich Inlet (Todd Inlet)	COS 2007; W & G 2006
	"considerable numbers"	Sight		Qualicum Beach	COS 2007; W & G 2006
	7		Killed	Barkley Sound (DFO patrol vessel with blade)	COS 2007; W & G 2006
	"large numbers"	Sight		Barkley Sound	COS 2007; W & G 2006
	some		Bycatch	Barkley Sound	COS 2007; W & G 2006
1956	several	Sight		Ballenas Island	COS 2007; W & G 2006
	4 (1 hit)	Sight		Saanich Inlet (Todd Inlet)	COS 2007; W & G 2006
	1		Killed	Saanich Inlet (Todd Inlet)	COS 2007; W & G 2006
		Sight		Saanich Inlet (Brentwood Bay)	COS 2007; W & G 2006
	several	Sight		Eagle Crest (near Qualicum)	COS 2007; W & G 2006
		Sight		Mistaken Island	COS 2007; W & G 2006
		Sight		Parksville	COS 2007; W & G 2006
1956	1	Sight		Qualicum Beach	COS 2007; W & G 2006
	105		Killed	Barkley Sound (DFO patrol vessel with blade)	COS 2007; W & G 2006
	"large numbers"	Sight		Barkley Sound	COS 2007; W & G 2006
	some		Bycatch	Barkley Sound	COS 2007; W & G 2006
	31 or 34		Killed	Pachena Bay	COS 2007; W & G 2006
	100s	Sight*		Pachena Bay	COS 2007; W & G 2006
1955		Sight		Fitzhugh and QC sounds	COS 2007; W & G 2006

Table B – 1. (Continued.)

Year	# of basking sharks	Encounters		Location	Source
		Live	Dead		
1955		Sight		Ucluelet (4 mi. offshore)	COS 2007; W & G 2006
	100s	Sight*		Cape Beale	COS 2007; W & G 2006
	65		Killed	Barkley Sound (DFO patrol vessel with blade)	COS 2007; W & G 2006
	many	Sight	Bycatch	Barkley Sound	COS 2007; W & G 2006
	1	Sight		Qualicum Beach	COS 2007; W & G 2006
1953	1		Dead	Campbell River	COS 2007; W & G 2006
1950s	7 or 8		Bycatch	Barkley Sound	COS 2007; W & G 2006
1952	some	Sight	Bycatch	Barkley Sound	COS 2007; W & G 2006
	7		Bycatch	West Coast Vancouver Island	COS 2007; W & G 2006
	3		Dead	West Coast Vancouver Island	COS 2007; W & G 2006
	1		Dead	Port Alberni	COS 2007; W & G 2006
	"school"	Sight		Brentwood Bay	COS 2007; W & G 2006
	1	Sight		Ladysmith	COS 2007; W & G 2006
1950	many	Sight	Bycatch	Barkley Sound	COS 2007; W & G 2006
1949	many	Sight	Bycatch	Barkley Sound	COS 2007; W & G 2006
1948	1		Dead	Parksville	COS 2007; W & G 2006
	8	Sight		Barkley Sound (Uchucklesit Harbor)	COS 2007; W & G 2006
1947	12	Sight		Texada Island	COS 2007; W & G 2006
	5		Dead	Texada Island	COS 2007; W & G 2006
	1000s	Sight		Rivers Inlet	COS 2007; W & G 2006
	1		Killed	Bamfield	COS 2007; W & G 2006
1946		Sight		Qualicum	COS 2007; W & G 2006
		Sight		Ucluelet	COS 2007; W & G 2006
	2		Killed	Bamfield	COS 2007; W & G 2006
1945-54	many	Sight	Bycatch	Barkley Sound-fisherman conflicts	COS 2007; W & G 2006
1944		Sight		La Perouse Banks	COS 2007; W & G 2006
	many	Sight		Rivers Inlet	COS 2007; W & G 2006
1943	1	Sight		Parksville	COS 2007; W & G 2006
	6		Killed	Rivers Inlet	COS 2007; W & G 2006
1942	1		Dead	Cortez Island	COS 2007; W & G 2006
	100s	Sight		Rivers Inlet	COS 2007; W & G 2006

Table B – 1. (Continued.)

Year	# of basking sharks	Encounters		Location	Source
		Live	Dead		
1941-47	~80		Killed	Barkley Sound commercial fishery	COS 2007; W & G 2006
1937	1	Sight		Prince Rupert	COS 2007; W & G 2006
1937-48	many	Sight	Bycatch	Rivers Inlet-fishermen conflicts	COS 2007; W & G 2006
1935	"numerous"	Sight		La Perouse Banks (25 mi. south of Pachena)	COS 2007; W & G 2006
~1934	"common"	Sight		BC coast	COS 2007; W & G 2006
1921	1000s	Sight		Alberni Canal	COS 2007; W & G 2006
1915	100s	Sight		Rivers Inlet	COS 2007; W & G 2006
1905	"common"	Sight		Queen Charlotte Islands	COS 2007; W & G 2006
1901	1		Dead	Rivers Inlet	COS 2007; W & G 2006
1897	"abundant"	Sight		Queen Charlotte Sound (probably Rivers Inlet area)	COS 2007; W & G 2006
1893	"another lot"	Sight		Nanaimo	COS 2007; W & G 2006
1892	~100	Sight		Qualicum	COS 2007; W & G 2006
1891	plentiful	Sight		Queen Charlotte Sound (probably Rivers Inlet area)	COS 2007; W & G 2006
1880		Sight		Queen Charlotte Islands	COS 2007; W & G 2006
1862	"plentiful"	Sight		Port Renfrew	COS 2007; W & G 2006
1858			Killed*	Clayoquot Sound	COS 2007; W & G 2006
1850s			Killed*	Nootka Sound	COS 2007; W & G 2006

Sight* is from an anecdotal or unverified source.
Dead: the available reference did not indicate whether the animal died as a result of human activities.
COS 2007: COSEWIC 2007
W & G 2006: Wallace and Gisborne 2006

Table B - 2. Summary of reported human encounters with basking sharks in the Pacific waters of the United States and Mexico.

Year	# of basking sharks	Encounters		Location	Source
		Live	Dead		
California					
2006	2 or 3	Sight		Big Sur	Van Sommeran p. c. 2007
2005	2 or 3	Sight		Big Sur	Van Sommeran p. c. 2007
2004	1	Survey		PFAS	Dotson pers. comm. 2007
2004	~2	Sight		Point Lobos	Mollet 2007
2003	1	Survey		Monterey Bay	Forney pers. comm. 2007
2002	3	Survey		Monterey/Morro Bay	Forney pers. comm. 2007
2002	3	Survey		Morro Bay	Forney pers. comm. 2007
2002	1	Sight		Monterey Bay	Van Sommeran p. c. 2007
2002	1(4.5 ext)		Bycatch	Drift net fishery	NMFS-SWR 2007
2001-04	2		Bycatch	Set net fishery	PFMC *et al.* 2006
2000	2,1,1	Sight		Monterey Bay	Monterey Bay Whale Watch 2000
2000	1	Tagged		Monterey Bay	Ugoretz 1999; Martarano pers. comm. 2007
2000	3	Sight		Monterey Bay	Van Sommeran p. c. 2007
1999	1	Survey		Morro Bay	Forney pers. comm. 2007
1994	≤20	Sight		Monterey Bay	Baduini 1995
1993	≤20	Sight		Monterey Bay	Baduini 1995
1993	3	Survey		Morro Bay	Forney pers. comm. 2007
1993	1(7.7ext)		Bycatch	Drift net fishery	NMFS-SWR 2007
1993	~2	Tagged		Monterey Bay	Ugoretz 1999; Martarano pers. comm. 2007
1993	3	Tagged		Monterey Bay	Van Sommeran pers. comm. 2007
1993	Many	Sight		Monterey Bay	Van Sommeran pers. comm. 2007
1992	30	Sight		Big Creek, Big Sur	Baduini 1995
1991	70 to 100	Sight		Monterey Bay	Black 1991
1991	~45	Tagged		Monterey Bay	Ugoretz 1999; Martarano pers. comm. 2007
1991	40	Tagged		Monterey Bay	Van Sommeran pers. comm. 2007
1991	7	Tagged		Monterey Bay	SWFSC 2006
1991	4 or 5	Sight		Monterey Bay	Baduini 1995
1991	15-20	Sight		Monterey Bay, North	Baduini 1995
1991	>40	Sight		Santa Cruz	Baduini 1995
1990	>38	Tagged		Monterey Bay	Van Sommeran p.c. 2007

Table B – 2 (Continued).

Year	# of basking sharks	Encounters		Location	Source
		Live	Dead		
California (Continued)					
1990	~10	Tagged		Monterey Bay	Ugoretz 1999; Martarano pers. comm. 2007
1989	20	Sight		Sta Barbara Channel Islands	Baduini 1995
late 1980s	"small school"	Sight		Monterey Bay	Thomas 2004
1985	8 avg	Survey		PFAS	Squire 1990
1983	2 avg	Survey		PFAS	Squire 1990
1981	27 avg	Survey		PFAS	Squire 1990
1979	8 avg	Survey		PFAS	Squire 1990
1977	10 avg	Survey		PFAS	Squire 1990
1976	>50	Sight		Carmel Bay	Hallacher 1977 in Baduini 1995
1973	<5	Survey		PFAS	Squire 1990
1972	<5	Survey		PFAS	Squire 1990
1971	<5	Survey		PFAS	Squire 1990
1970	<5	Survey		PFAS	Squire 1990
1969	<5	Survey		PFAS	Squire 1990
1967	10 avg	Survey		PFAS	Squire 1990
1966	140 avg	Survey		PFAS	Squire 1990
1965	9 avg	Survey		PFAS	Squire 1990
1964	60 avg	Survey		PFAS	Squire 1990
1963	47 avg	Survey		PFAS	Squire 1990
1963	1		Dead	Drake Bay	Springer and Gilbert 1976
1962	54 avg	Survey		PFAS	Squire 1990
1957-97	5		Killed	Partyboat fishery	Hill and Schneider 1999
1950	100-500	Survey		Monterey Bay	Squire 1967
1949	100-500	Survey		Monterey Bay	Squire 1967
1949	200		Killed	Monterey/Morro Bay	CITES 2002
1948	>2000	Survey		Monterey Bay	Squire 1967
1948	200		Killed	Monterey/Morro Bay	CITES 2002
1947	200		Killed	Monterey/Morro Bay	CITES 2002
1946	200		Killed	Monterey/Morro Bay	CITES 2002

Table B – 2 (Continued).

Year	# of basking sharks	Encounters		Location	Source
		Live	Dead		
California (Continued)					
1938	~25		Killed	Monterey Bay	Phillips 1948
1937	~25		Killed	Monterey Bay	Phillips 1948
1936	~25		Killed	Monterey Bay	Phillips 1948
1935	~25		Killed	Monterey Bay	Phillips 1948
1934	~25		Killed	Monterey Bay	Phillips 1948
1933	~25		Killed	Monterey Bay	Phillips 1948
1932	~25		Killed	Monterey Bay	Phillips 1948
1931	~25		Killed	Monterey Bay	Phillips 1948
1930	~25		Killed	Monterey Bay	Phillips 1948
~1929	500	Sight*		Monterey Bay	Chute 1930 in Squire 1967
1929	25		Killed	Monterey Bay	Phillips 1948
1928	25		Killed	Monterey Bay	Phillips 1948
1927	25		Killed	Monterey Bay	Phillips 1948
1926	25		Killed	Monterey Bay	Phillips 1948
late 1920s	15-20 common	Sight		Monterey Bay	Chute 1930 in Squire 1967
late 1920s	some		Bycatch	Monterey Bay	Chute 1930 in Squire 1967
1925	25		Killed	Monterey Bay	Phillips 1948
1924	25		Killed	Monterey Bay	Phillips 1948
early 1920s	100s	Sight		Monterey Bay	Thomas 2004
1880	"several"	Sight		Monterey Bay	Jordan 1987
1980	2		Killed	Monterey Bay	Jordan 1987
Washington, Oregon, Alaska, Hawaii, and Mexico					
2007	1	Sight*		Puget Sound, Washington	Evenson pers. comm. 2007
2003	1		Bycatch	Baja California, Mexico	Sandoval-Castillo *et al.* 2005
2003	1		Bycatch	Hawaii	PFMC *et al.* 2006
1999	1	Survey		Alaska	Gaichas pers. comm. 2007
1994	1	Sight*		Lincoln County, Oregon	Sandpiper 2007
1989	1		Bycatch	Puget Sound, Washington	Rupp pers. comm. 2007
late 1980s	1		Bycatch	Alaska	Gaichas pers. comm. 2007

Table B – 2 (Continued).

Year	# of basking sharks	Encounters		Location	Source
		Live	Dead		
Washington, Oregon, Alaska, Hawaii, and Mexico (continued)					
~1980	1		Bycatch	Prince of Wales Island, Alaska	Hulbert pers. comm. 2007
1943	1		Dead	Astoria, Oregon	Wallace and Gisborne 2006
1942		Sight		Puget Sound, Washington	Wallace and Gisborne 2006
1942		Sight		Puget Sound, Washington	Wallace and Gisborne 2006
1940		Sight		Puget Sound, Washington	Wallace and Gisborne 2006
1939	1		Dead	Puget Sound, Washington	Wallace and Gisborne 2006
1929	1		Bycatch	Cape San Lucas, Mexico	Chute 1930 in Squire 1967
~1868	"very abundant"	Sight*		Neah Bay, Washington	Swan 1968 in Wallace and Gisborne 2006
1862	1		Killed*	Neah Bay, Washington	Wallace and Gisborne 2006
1856			Killed*	Near Cape Flattery, Washington	Wallace and Gisborne 2006

p.c., pers. comm.
Sight*: from an anecdotal or unconfirmed source.
Dead: the available reference did not indicate whether the animal died as a result of human activities.
Ext: number of animals observed if extrapolated by total effort for the year.
PFAS, Pelagic Fisheries Aerial Survey, Santa Cruz to the Santa Barbara Channel Islands.
Note. 1962-85 average. number seen in block areas where seen.
Note. Tagging counts may have some overlap between projects

Table B - 3. Present day sightings of basking sharks in Canada's Pacific waters based on a survey of marine vessel operators, researchers, and educators. Table reprinted from COSEWIC (2007).

Date	Name/Affiliation	Location	Comments
1973	Gisborne, B. (Juan de Fuca Express water taxi)	Head of Bamfield Inlet, Barkley Sound	
1979	Stewart, Anne (BMSC, Public Education)	Trevor Channel, Barkley Sound	
1982	Stewart, Anne (BMSC, Public Education)	Trevor Channel, Barkley Sound	35' long
1984	Watson, Jane (Malaspina University College)	Trevor Channel, Barkley Sound	Present for a week
1999	Mitchell, Jim (DFO, South Coast Division)	48 39 50N, 124 50.8W; southwest coast Vancouver Island (off Nitnat)	12', in 8 m of water
2002	Kattler, D. (BC Ferries 2nd Officer)	30 miles SW of Rose Spit (53 43.1 131 18.95)	July

Table B - 4. Basking sharks caught in groundfish trawls off British Columbia between 1996-2004. Source: PacHarv Trawl *database (maintained at the Pacific Biological Station of Fisheries and Oceans Canada, Nanaimo, BC). Table reprinted from COSEWIC (2007).*

Fishing Year	Latitude	Longitude	Estimated Weight (kg)	Month	Fishing Depth (m)
1996	51.86	130.52	1134	May	288
2000	51.88	130.54	1134	February	353
2000	51.70	130.72	907.2	March	381
2004*	Rennell Sound		1350	August	Unknown

* Record confirmed from photograph taken onboard, not yet available in database.

Table B - 5. Location and distribution of basking sharks in British Columbia (by alphabetical order) and nearby adjacent waters based on historical records. Table reprinted from COSEWIC (2007).

Location	Year	No Sharks / Comments	Source
Alberni Canal	1921	Stopped vessel	Port Alberni News, August 31, 1921
Astoria, Oregon	1943	1- 2000 lb liver	The Fisherman, August 24, 1943, p. 2
Ballenas Island (light station)	1956		Colonist June 5 1956 p.13.
Barkley Sound (many locations)	1943-1969	Many sharks	Many sources (see Table B - 1)
Beaver Creek Wharf, North of Nanaimo	1893	"another lot of sharks"	Colonist, July 30, 1916
Bowen Island	1958	1	Sun August 29 1958 p.29.
Brentwood Bay	1952, 1956		Times Colonist, July 5 1952 p.11; Colonist June 5 1956 p 13
Clayoquot Sound	1973-1992		Summarized in Darling and Keogh (1994)
Cortes Island (Bliss Landing)	1942	1-1600 lb liver -dogfish net	The Fisherman, September 8, 1942, p. 3
Eagle Crest, Van. Island	1956		Colonist June 5 1956 p.13.
Esquimalt Harbour	1959	1 (23' long)	Times July 17 1959 p.27
Fitzhugh and QC sounds	1955		Province August 13 1955 p.20. (Mag. Sec.)
Gibsons (small island at the south end of Bowen Island)	1958	1 (27'10")	Sun September 11 1958 p.21.
La Perouse Banks	1935 1944	numerous sharks	Clemens (1935) Province, June 16, 1944, p. 5
Ladysmith	1952		Colonist June 28 1952, p.13.
Mistaken Island	1956		Colonist June 5 1956 p.13.
Namu (see Rivers Inlet)	1940-1948		Various
Neah Bay	1868		Swan (1868) in Wallace and Gisborne (2006)
North Saanich (Cole Bay)	1959	1 (not confirmed)	Colonist June 19 1959 p.21
Oak Bay	1958	Not confirmed	Times August 5 1958 p.15.
Pachena Bay	1956	31 or 34 (single largest kill-April)	Vancouver Sun May 16 1956
Parksville (Rathtrevor Beach)	1948 1956	1 (skeleton)	Vancouver Sun December 18 1948 p. 23. (confirmed by J.L. Hart at PBS) Colonist June 5 1956 p.13.
Parksville (Arbutus Point)	1943	1 (18' long)	Fisheries Research Board of Canada Progress Report 56 p. 15 (1943)
Port Alberni	1952	1 (15' 2000 lb)	Times Colonist July 9 1952 p.9.
Prince Rupert (Island Point)	1937 / 1938	1	The West Coast Fisherman, October 1990, p. 44-45.
Qualicum	1892; 1946; 1955; 1956	~100 1 1	Colonist, July 30, 1916; Colonist, Nov. 8 1946, p. 16. Colonist May 31 1955 p.24 Colonist June 5 1956 p.13
Queen Charlotte Sound (most likely Rivers Inlet area)	1891, 1897	plentiful	Green (1891) Gosnell (1897) in Wallace and Gisborne (2006)
Rivers Inlet	1915; 1940-1948	100s of sharks reported	Province, July 15, 1915, p. 3. Numerous newspapers and fishing magazines (see Table B – 1)
Saanich Inlet --Tod Inlet	1956 1956 1957	1 hit, 4 observed 1 (16.5', 2500 lbs)	Times April 20 1956 p.6 Colonist August 9 1956 p.1 Times November 28 1957 p.23
Texada Island	1947	12	Province, June 7 1947 p.5.
Uchucklesit Harbor (Barkley Sound)	1948	8	Times July 17, 1948 p.6.
Ucluelet	1946		West Coast Advocate, July 18 1946, p. 14.
Ucluelet (4 miles offshore)	1955		Colonist September 9 1955 p.13.

Table B - 6. Basking shark references directly transcribed from Barkley Sound Area Annual Fisheries Reports (1949-1969). Table reprinted from COSEWIC (2007).

Year	Comments transcribed from Reports	# killed
1949	Basking sharks appeared in Barkley Sound at the start of the sockeye season and did some damage to fishermen's nets. This year however they did not remain in the area as long as usual and damage was much lighter than it has been for the past few years.	
1950	Basking sharks appeared in large numbers during the sockeye season and did a great deal of damage to fishermen's nets.	
1952	Basking sharks did not appear so numerous in Barkley Sound this year and consequently damage to Sockeye gill-nets was not too serious.	
1955	Predators as usual inflicted their toll on fish and fishermen, with the basking shark again in the limelight. These sharks appeared in Barkley Sound in late February and remained a menace to gill-nets until June, at which time the bulk of them moved offshore where they hampered trolling operations. After rather futilely attempting to reduce their numbers by harpooning, permission was granted by the Department to have a knife-like weapon installed on the bow of the patrol vessel. This device, after a few strengthening modifications, proved very effective and a total of 65 sharks were killed during the year, evoking many favorable comments from fishermen. Basking sharks were again present in large numbers in and off Barkley Sound, causing considerable damage to trolling gear and nets. The knife installed on the FPC "Comox Post" to help combat this menace proved successful, with 65 being destroyed.	65
1956	Basking sharks were again present in large numbers in and off Barkley Sound. By use of the shark knife mounted on the FPC "Comox Post", 105 were destroyed, following which very few reports of net damage were received by fishermen.	105
1949	Basking sharks appeared in Barkley Sound at the start of the sockeye season and did some damage to fishermen's nets. This year however they did not remain in the area as long as usual and damage was much lighter than it has been for the past few years.	
1957	Basking Sharks: Were again present in and off Barkley Sound in quite large numbers, although evidently decreased from the previous year judging by the lighter net damage. Only 7 were destroyed by the use of the knife on the bow of the F.P.C. "Comox Post" due to the fact that the boat was in refit during the time the sharks were most prevalent.	7
1958	Basking Sharks: Were again present in quite large numbers but did not show on the surface very often during the hot summer. During October when the sharks were showing the "Comox Post" was in refit. However, during the season the "Comox Post" destroyed a total of 52 with the knife mounted on ht bow. Considerable net damage was caused by the sharks during October, and during the sockeye fishing in summer.	52
1959	Basking Sharks: Were as usual present in quite large numbers in Barkley Sound during the Spring, Summer, and Fall, and they were destroyed by means of the knife mounted on the FPC "Comox Post" whenever seen. During 1959 a total of 47 were destroyed in this manner. Considerable damage to salmon gillnets were reported throughout the season, mainly during the summer Sockeye fishery in Alberni Inlet.	47
1960	Basking Sharks: Were again very numerous in Alberni Inlet and Barkley Sound, causing considerable damage to gillnets. However, as they did not often show on the surface, only eleven were destroyed by the knife mounted on the bow of the FPC "Comox Post".	11

Table B – 6 (Continued).

Year	Comments transcribed from Reports	# killed
1961	Basking Sharks: Were as usual very numerous in Barkley Sound but, except for May and part of June, they did not often show, whle still doing considerable damage to salmon gillnets. From May 9th to August 10th 32 were destroyed by means of the knife mounted on the FPC "Comox Post". This was the total for the year.	32
1962	Basking Sharks: Were numerous in Barkley Sound, and 20 were destroyed by the knife on the FPC "Comox Post".	20
1963	Basking sharks were destroyed by the knife on the FPC "Comox Post", and in this manner 37 were destroyed during the year, compared to 21 last year, 32 in 1961, 11 in 1960, 47 in 1959, and 52 in 1958.	37
1964	Basking Sharks: Were quite numerous in Barkley Sound during the summer, but none were destroyed due to the absence of the refit of the FPC "Comox Post", which is the only vessel adapted to carry the shark knife.	0
1965	The destruction of basking sharks by the knife-equipped F.P.C. "Comox Post" was only 8, compared to none in 1964, 37 in 1963, 20 in 1962 and 32 in 1961.	8
1966	The destruction of basking sharks in the Barkley Sound subdistrict this year was nil. Although the FPC "Comox Post" has the knife located at Ecoole for quick attachment there were no basking sharks reported. For some reason this past year they were not showing at the surface.	0
1967	21 basking sharks were destroyed in Barkley Sound by the Departmental personnel using the Comox Post Shark Knife attachment. Three nets were destroyed by these fish in 1967. One was a total loss, and the other two were 60% losses. Several gillnets were damaged by basking sharks in the early part of the season. 21 sharks were destroyed in two days by the FPC "Comox Post". No damage to nets was reported after that date, and sightings of the animals decreased considerably.	21
1968	Trollers and one gillnetter reported basking sharks tangling up and destroying their gear on May 17th. The shark knife was installed and eight basking sharks were destroyed on May 22nd. The sharks then moved out of the area.	8
1969	No control program was carried out on the basking shark population. Six reports were received of nets being damaged and two nets were completely destroyed. One shark was strangled in a gillnet. The shark knife was installed on the FPC "Comox Post" with "nil" results.	0

Table B - 7. Sport caught basking sharks in British Columbia from newspaper records. Table reprinted from COSEWIC (2007).

Year	Location	Number reported	Month	Source
1947	Texada Island	5 killed, 5 misses, 2 unknown	June	Province, June 7 1947 p.5
1952	Brentwood Bay	School of basking sharks	July	Times Colonist, July 5 1952 p.11.
1952	West Coast VI	3 killed	July	Times Colonist, July 5 1952 p.11
1956	Saanich Inlet	1 killed	April	Colonist, April 20 1956 p.1
1957	Qualicum Beach	"Considerable numbers"	June	Colonist, June 5 1956 p. 13

Table B - 8. Basking shark sightings in central California since 1990, from multiple sources (refer to text).

Year	Drift Net fishery	PSRF	CDFG Tagging Program	Billfish Tagging Program	MBWW	NMFS Porpoise/ turtle	Total
1990	x	38	some of 58	x			38++
1991	x	40	most of 58	7		0	40+
1992	x	x	x	x			0
1993	1	3+s	some of 58	x		3	4+
1994	x	x	x	x			0
1995	x	x	x	x		0	0
1996	x	x	x	x			0
1997	x	x	x	x	x	0	0
1998	x	x	x	x	x		0
1999	x	x	x	x	x	1	1
2000	x	3s	some of 58	x	4	0	7+
2001	x	x	x	x	x	0	0
2002	1	1s	x	x	x	6	8
2003	x	x	x	x	x	1	1
2004	x	x	x	x	x	0	0
2005	x	2/3s	x	x	x	0	3
2006	x	2/3s	x	x	x	0	3

X=survey occurred by no sighting or tagging; s=sighting but no tagging; +s=some tagged and sighted but number sighted unknown;
PSRF=Pelagic Shark Research Foundation
(http://www.pelagic.org/montereybay/pelagic/baskingshark.html)
CDFG=California Department of Fish and Game, MBWW=Monterey Bay Whale Watching.

Table B - 9. Basking sharks observed on harbour porpoise and leatherback turtle surveys conducted from 1991 to 2003 on the coast of California by NOAA / NMFS. Morro Bay is actually south-central California (Benson et al. *2007; Carretta and Forney 2004; Forney, pers. comm. 2007).*

	Morro Bay		Monterey Bay	
Year	**Area surveyed (km)**	**No. sharks**	**Area surveyed (km)**	**No. sharks**
1991	922	0	509	0
1993	1643	3	860	0
1995	1197	0	730	0
1997	1492	0	860	0
1999	1317	1	585	0
2000	0	0	74	0
2001	0	0	368	0
2002	1652	3	812	3
2003	0		334	1

Table B - 10. History of reported human encounters with basking sharks in the North Pacific.

Year	Number of basking sharks	Encounters		Location	Source
		Live	Dead		
1990	54*		Bycatch	North Pacific high seas driftnet fisheries	Bonfil 1994
1967-70	19		Bycatch	North Pacific Japanese tuna longline fisheries	Nakano 1999

*This is an extrapolation from single animals recorded by observers of catches in each of the squid and large mesh net fisheries of 1990

Appendix C: Simulation modeling to explore recovery potential of endangered basking shark populations

INTRODUCTION

The recovery potential of the Pacific population of basking sharks, *Cetorhinus maximus*, was assessed using a production model. Potential catch histories and scenarios for future recovery were simulated. Two catch histories are evaluated; 1) a minimum history for catches in Canada and the US, consisting of 3,725 individuals killed between 1920 and 1979 (catch history 1), and 2) a maximum history for catches in Canada and the US, comprised of 5,925 individuals killed similarly between 1920 and 1979 (catch history 2). Recovery potential is assessed by identifying the number of years it would take the population to reach 1000 breeding pairs given the assumption that the population has a 50:50 sex ratio distribution i.e., a total size of 2000 mature sharks, and assuming that the population consists of either 25%, 30%, 40%, 50% or 75% mature individuals from year 2007 and on. Recovery target points also include the amount of time the population needs to return to its unfished abundance and to 30%, 40% and 50% of that unfished abundance. Target biomass reference points include the time it would take the population to return to 30%, 40%, 50% and 99% of the initial biomass size. Also included are reference points specifying what level of fishing mortality can be sustained if the stock is to retain its current status into the future.

An age-structured model was constructed in addition to the production model to confirm the recovery conclusions produced in the production model, by comparing the model estimates of the length of time it would take to reach the recovery target points. Data availability, particularly the absence of data on information on Goodyear's recruitment compensation parameter (Goodyear 1980) or equivalently regarding the fishing mortality rate policy that would produce the maximum sustainable yield (see Martell *et al.* in press), limited the applicability of this model.

METHODS

The production model is a logistic growth model that assumes no error in reported catch (equation 1).

(1) $$N_{t+1} = N_t + r_{\max} N_t \left(1 - \frac{N_t}{K}\right) e^{wt} - C_t$$

N_t are numbers in year t, r_{max} is the maximum intrinsic rate of population growth (i.e., net production; growth + new production – natural mortality), $\hat{N}$ is the unfished population size expressed as numbers of individuals, wt are independent process errors at time t, C_t is the observed catch in numbers of individuals in year t, and t is time indexed from 1920 to 2007. The production model is density-dependent, and the size at which production is maximized, $\hat{N}_{50\%}$, is given by the inflection point of the derivative of the yearly population change (N_{t+1} –N_t) with respect to N, i.e., where it is zero (equation 2).

(2) $$\frac{\partial(N_{t+1} - N_t)}{\partial N} = r_{\max} - \frac{2 r_{\max} \hat{N}_{50\%}}{\hat{N}} = 0 \quad \Rightarrow \quad \hat{N}_{50\%} = \frac{\hat{N}}{2}$$

To resolve the confounding between the parameters r_{max} and $\hat{N}$ the population is required to have exhibited both recovery and decline (Hilborn and Walters 2002). For the basking shark population, there is very limited information and we use uniform priors for r_{max} and $\hat{N}$ to represent plausible, but equally likely, hypotheses regarding these values.

Population trajectories are modeled using a stochastic approach to stock reduction analysis (SRA). SRA is a method that was first introduced by Kimura and Targat (1982). Using SRA we can identify hypotheses, consisting of the population parameters r_{max}, $\hat{N}$ and a series of random recruitment anomalies wt, which are consistent with the observed catch time series and current population level relative to the original population size. The model is driven by observed catch (see equation 1), and it is assumed that in the initial year (1920) the population size was unfished, i.e., $N_{1920} = \hat{N}$. The stochastic SRA generates population trajectories conditional on parameter combinations of r_{max} and $\hat{N}$.

The status of the Pacific population of basking sharks, more specifically, the probability that the Pacific population of basking sharks has decreased by some 90% between the years 1920 and 2007 was then determined. Given what we know about anthropogenic removals, and assuming that the stock followed a stationary production relationship with mean r_{max} with realistic variation and unfished populations size $\hat{N}$, a method referred to as Bayesian stochastic SRA (SSRA) (Walters *et al.* 2006) could be employed. SSRA consists of the following four steps. First, thousands of population scenarios are constructed by randomly drawing the population parameters r_{max} and $\hat{N}$ and the process errors, or recruitment anomalies, *wt*, from their respective priors. Second, population trajectories are generated by simulating the population scenarios conditional on observed catches. Third, the likelihood that each population decreased by 90% between 1920 and 2007 is calculated. Finally, the trajectories are re-sampled, with sample probability proportional to the likelihoods calculated in step 3. This gives us a posterior probability density function for the population parameters.

Model initialization

The prior distribution for r_{max} is assumed to be uniform between 0.032 and 0.04, based on deterministic life history table analysis and Monte Carlo simulation model results reported in Campana *et al.* (2008). The prior on carrying capacity is assumed to be uniform, with bounds of 500 and 10,000. The standard deviation in process and observation errors are calculated from a total error term, $\mathrm{T} = 1$, assumed to be equally distributed, that is, $\tau = \sigma = \sqrt{0.5}\sqrt{\mathrm{T}}$. The process error terms are drawn from a prior distribution with a mean of zero, and standard deviation τ.

Two catch histories are modeled. Catch history 1 is the minimum hypothesis for Canadian and US catches. For Canada, 40 basking sharks per year are assumed to have been caught between 1945 and 1969, while for the US, 25 basking sharks per year are assumed to have been caught between 1920 and 1945, 200 per year between 1946 and 1952 and 25 per year between 1953 and 1979 (COSEWIC 2007). This adds up to a total mortality of 3,725 basking sharks in the Pacific for catch history 1. Catch history 2 is the maximum hypothesis for Canadian and US catches. For Canada 100 basking

sharks per year are assumed to have been caught between 1945-1969, while for the US, 25 baskin shakrs per year are assumed to have been caught between 1920 and 1945, 300 per year between 1946 and 1952, and 25 per year between 1953 and 1979 (COSEWIC 2007). This adds up to a total mortality of 5,925 basking sharks for catch history 2. For 1980-2007, the years where no catch is specified, human induced incidental mortaliy, C_t is assumed to be determined by $C_t = F_t N_t$, where F is a fishing mortality rate and N is numbers at time t. It is assumed that the entire population is vulnerable, and F is randomly chosen from $F=0$ or $F=0.05*M$, where M = 0.068 is the natural morality rate of basking sharks (Pauly 2002).

Model likelihood

The likelihood of the population being at 10% of the unfished population size $\hat{N}$ in 2007 is given in equation (3).

$$(3) \qquad L(N_{2007} = 0.1\hat{N} \mid r_{max}, \hat{N}, wt) = \log(\sigma) + \frac{1}{2}\log(2\pi) + \frac{\left(\log\left(\frac{\hat{N} - N_{2007}}{\hat{N}}\right) - \log(0.9)\right)^2}{2\sigma^2}$$

Where σ is the standard deviation in the observation that the population has decreased by 90% in year 2007.

The model produces 100,000 sample trajectories, which are then resampled, based on their importance weight/likelihood, using the sampling importance resampling method as recommended by Schnute (1994) and McAllister and Ianelli (1997).

RECOVERY SCENARIOS

To assess the recovery potential for the Pacific population of basking sharks, we model a number of scenarios. The first five of these include the time for the population to recover to 1000 breeding pairs, assuming a 50/50 sex ratio and that either 25%, 30%, 40%, 50% or 75% of the population is mature. Additionally, the number of years the population requires to return to 30% ($\hat{N}_{30\%}$), 40% ($\hat{N}_{40\%}$), 50% ($\hat{N}_{50\%}$, where the stock is at its most productive level i.e. $\hat{N}_{MSY}$), and 99% of the unfished population size $\hat{N}$ are determined. Also calculated is the length of time it takes for the population to reach 30% ($\hat{B}_{30\%}$), 40% ($\hat{B}_{40\%}$) and 50% ($\hat{B}_{50\%}$) and within 99% of $\hat{B}$, where $\hat{B}$ is the unfished population size expressed as biomass in tonnes (t). To do this we assume that an individual in the population has an average weight of 2.07t in the unexploited population, which decreases to 1.5t when the population is depleted to 10% of its original size. To determine a relationship between the depletion level and average weight we linearly interpolate between the two assumed average weights (equation 4). This provides us with a proxy for average weight without including age-structure in the model.

$$(4) \qquad \overline{w} = 0.63(1-x) + 1.44 \; tonnes$$

In equation 4 $\overline{w}$ is the average weight of an individual in the population when the population is depleted by x percent.

Model Results

Population trajectories

Under the assumption that the population was unfished prior to 1920, the model assumes that the abundance of basking sharks had declined by 90% in 2007 and estimates that r_{max} was in the range 0.032 – 0.04. For catch history 1 (minimum hypothesis), the model predicts that the unfished population size $\hat{N}$ was 2,970 (2,729 – 3,183), while for catch history 2 (maximum hypothesis), the model predicts that the unfished population size $\hat{N}$ was 4,822 (4,469 – 5,116) (Table C - 1). The current population size N_{2007} is predicted to be 321 (36 – 678) and 535 (62 – 1,089) when modeling catch histories 1 and 2 respectively.

Table C – 1. Posterior distribution means and 95% confidence intervals (in parentheses) for the unfished population size ($\hat{N}$), current population size, (N_{2007}) and intrinsic growth rate (r_{max}) for catch histories 1 (minimum hypothesis) and 2 (maximum hypothesis).

	Catch history 1	Catch history 2
$\hat{N}$	2,970 (2,729 – 3,183)	4,822 (4,469 – 5,116)
N_{2007}	321 (36 – 678)	535 (62 – 1,089)
r_{max}	0.0356 (0.0321 – 0.0397)	0.0355 (0.0322 – 0.0398)

The mean population trajectories, and the 75% and 95% confidence intervals for the hypothesized minimum and maximum catch histories are shown in Figures C – 1 and C- 2.

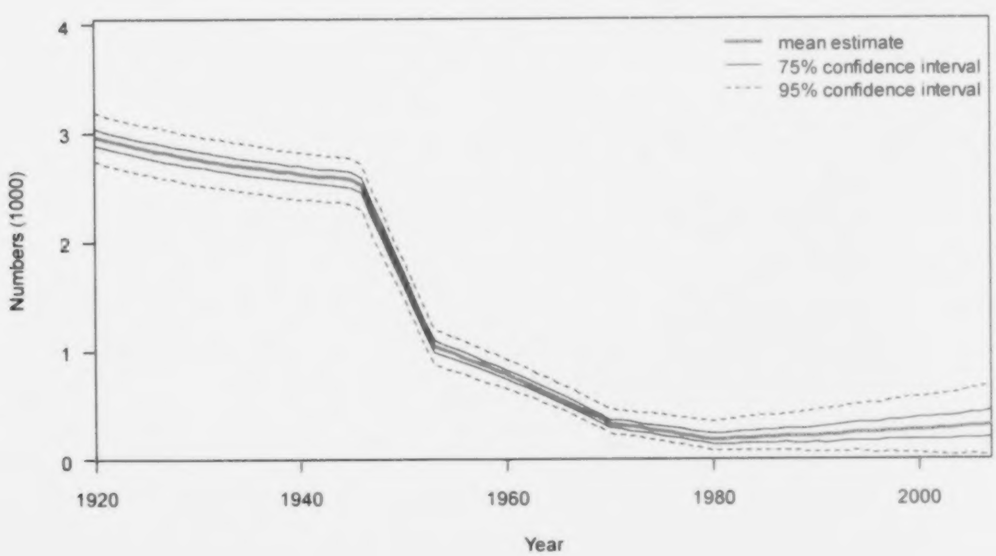

Figure C – 1. Catch history 1 population trajectories for basking sharks. The thicker solid line shows the mean estimate, the thinner solid lines show the 75% confidence interval and the dotted lines show the 95% confidence interval.

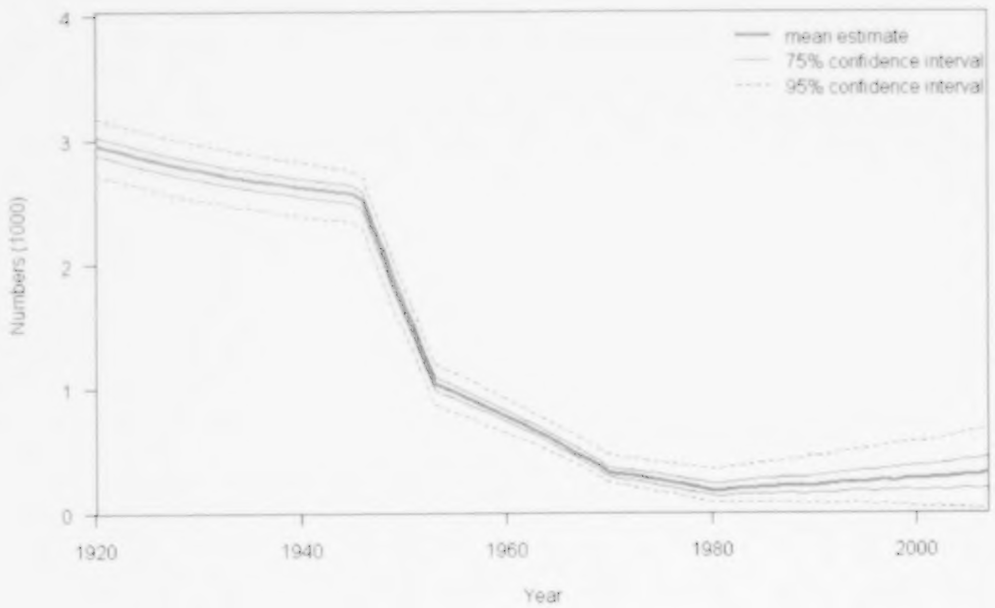

Figure C – 2. Catch history 2 population trajectories for basking sharks. The thicker solid line shows the mean estimate, the thinner solid lines show the 75% confidence interval and the dotted lines show the 95% confidence interval.

Population reference points

Target reference points for the Pacific population of basking sharks include numbers of breeding pairs , numbers of individuals relative to the original or unfished population size, $\hat{N}$ and biomass relative to the original or unfished biomass, $\hat{B}$. The model produces a population trajectory and 95% confidence intervals. For each of the estimates of the population size in year 2007 (i.e., the mean, 2.5th, and 97.5th percentile), four scenarios were run, one for each hypothesis about future human induced mortality. The four future scenarios are *F*=0, i.e., no human induced mortality, and *F*=0.05M, *F*=0.5M, and *F*=M to represent hypotheses about credible incidental and targeted human-induced mortality for these basking sharks.

Figure C – 3 shows the mean population trajectory (numbers of fish) for catch history 2 (minimum catch history) in the black lines from 1920 – 2007. From 2007 on, four blue/grey lines extend representing the four future scenarios. The dotted line shows the point (year 2195, i.e. in 188 years) where the *F*=0 future scenario returns to within 99% of the predicted unfished population size. For *F*=0.05M the population does not recover to its unfished size within 500 years, but does recover to $\hat{N}_{50\%}$ in 71 years, i.e., by year 2078.

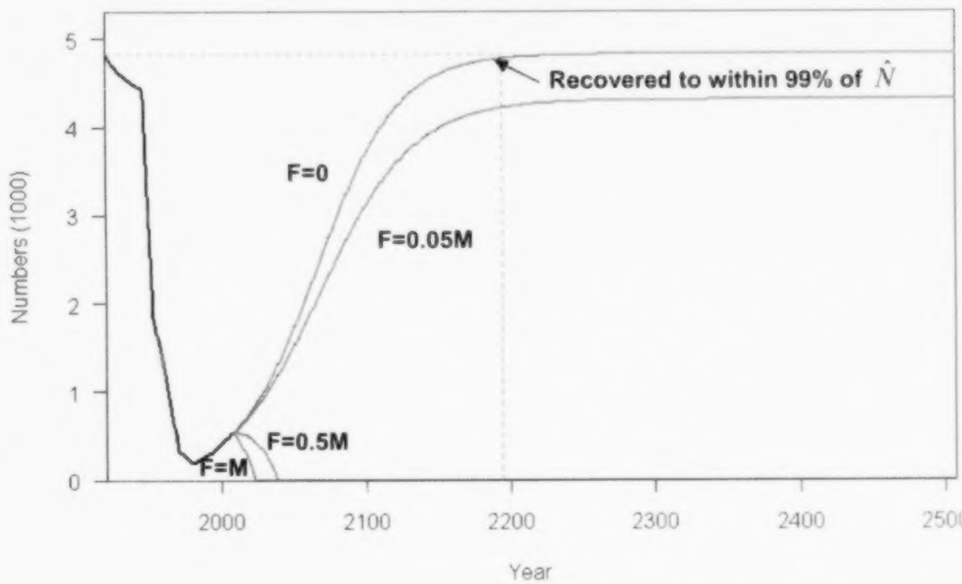

Figure C – 3. Population decline and recovery for basking sharks 1920 – 2507. The mean population trajectory is plotted (black line) for 1920 – 2007 (catch history 2), where after the four scenarios F*=0,* F*=0.05M,* F*=0.5M and* F*=M are plotted in the blue/grey lines. The dotted lines show the year that the population recovered to within 99% of the unfished population size* $\hat{N}$.

For two future scenarios *F*=0.5M and *F*=M, the population becomes extinct within approximately 20-30 years. In fact, this is the case for all the future scenarios we run for each suite of population reference points, and therefore we do not include these in the results in Tables C - 2, C - 3 and C - 4.

The lengths of time it takes for the population to recover to 1,000 breeding pairs for catch histories 1 and 2 are presented in Table C - 2. If 40% of the population is mature, it would take more than 500 years assuming catch histories 1 or 2 , for the basking shark population to recover to 1,000 breeding pairs if there is no anthropogenic mortality. The assumption that 40% of the fish are mature in the initial population size is discussed in the age-structured model.

The lengths of time required for the population to recover to within 30% of $\hat{N}$ ($\hat{N}_{30\%}$), 40% of $\hat{N}$ ($\hat{N}_{40\%}$),50% of $\hat{N}$ ($\hat{N}_{50\%}$) and to within 99% of $\hat{N}$ for catch histories 1 and 2 are presented in Table C - 3. For both catch histories, the time required for the population to recover to $\hat{N}_{30\%}$ is 37 years, to $\hat{N}_{40\%}$ is 49-50 years, and to $\hat{N}_{50\%}$ is 60-61 years, i.e. by year 2067 or 2068, assuming F=0. If some anthropogenic mortality occurs at the F=0.05M level, the recovery time frame is extended to 43 years for $\hat{N}_{30\%}$, 58 years for $\hat{N}_{40\%}$, and 72 years for $\hat{N}_{50\%}$, i.e., by the year 2079. The populations do not recover within 500 years for F=0.5M and F=M, and are thus not included in the table. The reason why the recovery times are almost identical for each of the two scenarios is that both populations are depleted by 90% and grow at a fixed percentage of the total population each year in the recovery (beyond the year 2007) phase. The amount of time it would take for the population to return to within 99% of $\hat{N}$ is estimated as 188-189 years in the F=0 scenario for catch histories 1 and 2 respectively. In the F=0.05M scenario, the population will not return to $\hat{N}$; it can not, by definition, as long as the stock is being fished.

Both catch histories follow similar trends in the length of time required for recovery to the biomass reference points (Table C-4). The model suggests that for the F=0 and F=0.05 scenarios it will take 46 or 52 years, respectively (i.e., by year 2053 or 2059), for the population of basking sharks to return to 30% of $\hat{B}$, from B_{2007} (equation 5). Note that this is only 7% of $\hat{B}$ due to the lower average weight (1.5 t per shark) of sharks in a population that is depleted to 10% of its original size, compared to the average weight of sharks in an unexploited population (2.07 t per shark).

(5) $$B_{2007} = \frac{0.1*\hat{B}*1.5}{\hat{B}*2.07} = \frac{1.5}{10*2.07} = 0.07\hat{B}$$

Table C - 2. Target reference points in terms of breeding pairs. The table shows the number of years it takes for the population to recover to 1,000 breeding pairs for catch histories 1 and 2, given 5 hypotheses (25%, 30%, 40%, 50% and 75%) about the percentage of mature individuals in the population. The values in parentheses are the 95% confidence intervals generated by starting the 2007 population from its associated 95% confidence interval.

	Years, assuming *F*=0	**Years, assuming *F*=0.05*M***
25% Mature		
Catch history 1	500+	500+
Catch history 2	500+	500+
30% Mature		
Catch history 1	500+	500+
Catch history 2	500+	500+
40% Mature		
Catch history 1	500+	500+
Catch history 2	500+ (114 - 500+)	500+
50% Mature		
Catch history 1	500+	500+
Catch history 2	105 (66 - 202)	146 (85 - 500+)
75% Mature		
Catch history 1	122 (76 – 253)	500+ (105 – 500+)
Catch history 2	66 (37 – 148)	79 (43 – 181)

Table C - 3. Target reference points in terms of the original population size in numbers. The table shows the number of years it takes for the population to recover to $\hat{N}_{30\%}$, $\hat{N}_{40\%}$, $\hat{N}_{50\%}$ and 99% of $\hat{N}$. The values in parentheses are the 95% confidence intervals generated by starting the 2007 population from its associated 95% confidence interval.

	Years, assuming *F*=0	**Years, assuming *F*=0.05*M***
Recovery to $\hat{N}_{30\%}$		
Catch history 1	37 (13 – 110)	43 (15 – 129)
Catch history 2	37 (13 – 109)	42 (15 – 128)
Recovery to $\hat{N}_{40\%}$		
Catch history 1	50 (24 – 124)	58 (28 – 147)
Catch history 2	49 (24 – 123)	57 (28 – 146)
Recovery to $\hat{N}_{50\%}$		
Catch history 1	61 (35 – 137)	72 (40 – 165)
Catch history 2	60 (35 – 136)	71 (40 – 163)
Recovery to within 99% of $\hat{N}$		
Catch history 1	189 (149 – 278)	Never
Catch history 2	188 (148 – 277)	Never

Table C - 4. Biomass reference points. The table shows the number of years it takes for the population to recover to 30%, 40% and 99% of the original or unfished biomass $\hat{B}$. The values in parentheses are the "95% confidence intervals" generated by starting the 2007 population from its associated 95% confidence interval.

	Years, assuming *F*=0	**Years, assuming *F*=0.05*M***
Recovery to 30% of $\hat{B}$		
Catch history 1	46 (21 – 120)	53 (24 – 142)
Catch history 2	46 (21 – 119)	52 (24 – 141)
Recovery to 40% of $\hat{B}$		
Catch history 1	59 (32 – 134)	69 (37 – 161)
Catch history 2	58 (32 – 133)	67 (37 – 159)
Recovery to 50% of $\hat{B}$		
Catch history 1	70 (42 – 146)	83 (50 – 179)
Catch history 2	69 (42 – 145)	82 (49 – 177)
Recovery to 99% of $\hat{B}$		
Catch history 1	196 (155 – 286)	Never
Catch history 2	195 (155 – 285)	Never

Recovery to 40% of $\hat{B}$ is predicted to take 58 and 69 years for *F*=0 and *F*=0.05, respectively (i.e. by year 2065 and 2076). Recovery to 50% of $\hat{B}$ is predicted to take 69 and 83 years for *F*=0 and *F*=0.05M, respectively (i.e. by year 2076 and 2090). Recovery to within 99% of $\hat{B}$ is predicted to take 196 years for *F*=0 (i.e. by year 2203). When *F*=0.05M, the population will not return to within 99% of $\hat{B}$ as the anthropogenic mortality keeps the population at a lower level. This agrees closely with the estimates of time to recover to 99% of $\hat{N}$ from Table C - 3. The estimates in Table C - 4 are slightly higher, because the oldest and heaviest animals recover last, as the population returns to its unexploited state.

The fishing mortality rate (F_t) that the population can sustain without suffering further decline from the 2007 population size is 0.032 (0.031 – 0.032) or 47% (46-47%) of the natural mortality rate (Table C - 5). This is the case for both catch histories 1 and 2. In terms of numbers of basking sharks killed annually it is 10 (1 – 21) for catch history 1 and 17 (2 – 34) for catch history 2 (Table C - 5).

Table C - 5. To sustain the population at its current size, the following fishing mortality rates should be applied to the population. The required fishing mortality is additionally specified in terms of a proportion of M and as a number of sharks killed per year.

	Catch history 1	**Catch history 2**
F_t equilibrium	0.0317 (0.0312 – 0.0317)	0.0316 (0.0313 – 0.0317)
F_t as a proportion of M	0.466 (0.459 – 0.466)	0.465 (0.461 – 0.466)
F_t as number of basking sharks killed per year	10 (1 – 21)	17 (2 – 34)

AGE-STRUCTURED MODEL EXPLORATION

To explore questions related to age structure and average weight of the population, an age-structured delay-difference model was constructed. The model consists of the input parameters L_∞, k, t_o, $\dot{a}$, M and r (Table C - 6).

Table C - 6. Age-structured model input parameters. All parameter values are from Pauly (2002).

Parameter	Value	Definition
L_∞	10m	Asymptotic length
k	0.062	von Bertalanffy growth coefficient
t_o	-2.46	Time at length zero
$\dot{a}$	0.0075	Length-weight relationship scalar
M	0.068	Natural mortality rate
r	> 50 years	The maximum age group, assumed to be 100 for this model

The model estimates the parameters R_o, κ, a_h, and γ for ages 0 to 20 (Table C - 7). Vulnerability at age is assumed to be 1 for ages 21 to r).

Table C - 7. Parameters estimated by the age-structured model.

Parameter	Definition
R_o	the equilibrium age 0 recruits
κ	Goodyear's recruitment compensation ratio (Goodyear 1980)
a_h	the age at 50% vulnerability
γ	standard deviation

The model derives the following parameters from the leading parameters: survivorship (lx_a), vulnerability-at-age (v_a,) length-at-age (l_a), weight-at-age (w_a), the spawning stock biomass at equilibrium (sB_o), the maximum survival rate from egg to age 1 recruit (α), a density dependent term (β), the unfished population size in numbers (N_o) and the unfished biomass (B_o), where a is age (Table C- 8).

Age of maturity for females is 16-20 years (COSEWIC 2007), thus we assume that for females ages 0-15 are immature, 20% of age 16s are mature, 40% of age 17s, 60% of age 18s, 80% of age 19s and all sharks 20 years of older are mature. The age of maturity for males is 12-16 years (COSEWIC 2007), thus we assume that ages 0-11 are immature, 20% of ages 12, 40% of ages 13, 60% of ages 14, 80% of the ages 15 and all age 16 and older sharks are mature. This gives us a mean maturity, mat_a, of 10% of age 12, 20% of age 13, 30% of age 14, 40% of age 15, 60% of age 16, 70% of age 17, 80% of age 18, 90% of age 19 and all age 20 and older sharks are mature.

Model estimates are very sensitive to initial values of κ and R_o because there is no information to resolve the confounding in these parameters. An alternative parameterization from Martell *et al.* (in press), where κ is calculated from an estimate of F_{MSY} cannot resolve this confounding. A conservative prior for F_{MSY}, i.e., with mean 0.6*M (S.J.D. Martell, pers. comm.) results in values of

Table C- 8. Parameters derived for the leading parameters.

Symbol and Equation	Description
$lx_a = 1, a = 1$ $lx_a = lx_{a-1}e^{-M}, a > 1$ $lx_r = \frac{lx_{r-1}e^{-M}}{1-e^{-M}}, a = r$	Survivorship
$v_a = \frac{1}{1+e^{-\gamma(a-a_h)}}, \quad 1 \le a \le 20$ $v_a = 1, \quad a \ge 21$	Vulnerability at age
$l_a = L_\infty(1-e^{-k(a-to)})$	Length-at-age
$w_a = \dot{a}\, l_a^3$	Weight-at-age
$sB_o = \sum_a wa * lx * mat$	Spawning stock biomass at equilibrium
$\alpha = \frac{\kappa R_o}{sB_o}$	Maximum survival rate frm egg to age 1 recruit
$\beta = \frac{\kappa - 1}{sBo}$	Density dependent term
$N_a = \sum_a Ro\, lx_a$	Unfished equilibrium numbers
$B_o = \frac{R_o}{1-e^{-M}}$	Unfished equilibrium biomass

κ close to 5, which is common for many fish species, but likely much too high for basking sharks. For these reasons, we briefly explore the model results, but do not rely exclusively on this model for conclusions, even though the model structure enables us to calculate some of the age-structure dependent target reference points that had to estimated above.

The age-structured model proceeds by calculating the numbers of fish in the year 1920, $N_{t=1920,a=1} = R_o lx_a$, where *t* is the subscript for time and *a* is the subscript for age. For *t* = 1921 to *t* = 2007 numbers at time are calculated according to equation 6:

$$N_{t,a} = \frac{\alpha \sum_a N_{t-1,a} w_a mat_a}{1 + \beta \sum_a N_{t-1,a} w_a mat_a}, \qquad a = 1$$

(6) $$N_{t,a} = N_{t-1,a-1} e^{-(M+v_{a-1}F_t)}, \qquad a > 1$$

$$N_{t,r} = N_{t-1,r-1} e^{-(M+v_{a-1}F_t)} + N_{t-1,r} e^{-(M+v_{a-1}F_t)}, \quad a = r$$

In equation 6, F_t is the mortality in year *t*, and v_a is the vulnerability to the fishing gear at age *a* which is an estimated parameter when *a*<21. For years where catch is

observed, F_t is calculated analytically using the Newton-Raphson method, which assumes there are no errors in reported catch. The algorithm is initialized by setting $Ft_t = C_t/B_t$, and then updating Ft_{t+1} until the difference between observed and predicted catch is small. The observed F_t is calculated as the zero derivative of the catch equation (equation 7).

$$
C_t' = \sum_a \frac{N_a w_a v_a (1 - e^{-(M + v_a F_t)})}{M + v_a F_t} - \frac{N_a w_a F_t v_a^2 (1 - e^{-(M + v_a F_t)})}{(M + v_a F_t)^2} + \frac{N_a w_a F_t v_a^2 e^{-(M + v_a F_t)}}{M + v_a F_t} \tag{7}
$$

The Newton-Raphson algorithm converges quickly, within 5-7 iterations, but the method is set to run for 30 iterations or until the difference between consecutive iterations is less than 0.001. To ensure that the solution has converged, we check that observed and predicted catches are identical.

Parameters were estimated using ADMB© (Otter Research Ltd., Sydney, British Columbia). A negative log-likelihood is used and given by equation 8, where the standard deviation *sig* is assumed to be 0.05.

$$
L(N_{2007} = 0.1K \mid R_o, \kappa, v_a, wt) = \log(2\pi) + \log(sig) + \log\left(\frac{K - N_{2007}}{K}\right) + \frac{\left(\log\left(\frac{K - N_{2007}}{K}\right) - \log(0.9)\right)^2}{2 * sig^2} \tag{8}
$$

Age-structured model results

In the unexploited population 39% of sharks are mature, regardless of the size of the unexploited population. Thus, the target reference points which assume that the percentage of the population that is mature is 25%, 30% or 40% are likely more realistic scenarios than those which assume 50% or 75%. The latter are unrealistically high proportions, unless immature animals have been disproportionably targeted.

The average weight-at-age in the population is 2.07 tons in the unexploited state. However, as the population decreases to 10% of its original size this is reduced to 1.5 tons per average shark. This is the basis for the weight relationship used in equation 4.

The model estimates for numbers in the initial year are higher than estimates produced by the production model (Table C - 9). Goodyear's compensation ratio (Goodyear 1980) is estimated to be approximately 1.49 and 1.69, which is low and agrees well with our assumptions about basking shark life history.

Table C - 9 . Age-structured model estimates of No, Ro *and* κ. *Values in parentheses are listed for comparison and are from the production model, see Table C - 1.*

	N_0	R_0	κ
Catch history 1	3,513 (2,970)	231	1.69
Catch history 2	5,887 (4,822)	387	1.49

Target reference points are listed Table C - 10 and, again, these are higher than the estimates produced by the production model. For both numerical and biomass target reference points, results are reported only for F=0 and F=0.05M. As in the production model, human induced mortalities of F=0.5M and F=M will cause the populations to go extinct, although, for the age-structured model this takes longer, about 100-200 years depending on the scenario.

Table C - 10 . Age-structured model estimates of target reference points. Values in parentheses are listed for comparison and are from the production model, see Tables C - 2 and C - 3. The values listed for comparison for the breeding pairs target points assumes 40% of the population was mature in the production model.

	Years, assuming F=0	**Years, assuming F=0.05M**
Recovery to 1000 breeding pairs		
Catch history 1	500+ (500+)	500+ (500+)
Catch history 2	374 (500+)	500+ (500+)
Recovery to $\hat{N}_{30\%}$		
Catch history 1	73 (37)	92 (43)
Catch history 2	97 (37)	135 (42)
Recovery to $\hat{N}_{40\%}$		
Catch history 1	98 (50)	126 (58)
Catch history 2	130 (49)	185 (57)
Recovery to $\hat{N}_{50\%}$		
Catch history 1	121 (61)	160 (72)
Catch history 2	160 (60)	238 (71)
Recovery to 99% of $\hat{N}$		
Catch history 1	396 (189)	Never (Never)
Catch history 2	500+ (188)	Never (Never)

Biomass reference points for the age-structured model are listed in Table C - 11. These are consistently estimated to be higher than was estimated in the production model for both catch histories. On average, it will take a century (87-111 years depending on which catch history is more accurate) for the stock to return to 30% of $\hat{B}$ assuming that there is no future human induced mortality. If a low level is allowed, this time increases to 111 - 156 years. Time for recovery to 40% of $\hat{B}$ is 112-144 years depending on the catch history and assuming no incidental mortality, and 146-208 years assuming a low level of human induced mortality. Recovery to 50% of $\hat{B}$ is estimated to take 135-174 years assuming no anthropogenic mortality and 182-265 years assuming the fishing mortality rate increases to 0.05M. Recovery to unfished biomass levels is estimated to take over 500 years for catch history 2, which is larger than the time estimated for the numbers to return to $\hat{N}$, reflecting the conservative nature of this

model. However, all these results are highly sensitive to initial parameter values. Without good information on which to base the construction of priors, these initial guesses could be misleading.

Table C - 11 . Age-structure model estimates of biomass reference points. Values in parentheses are original depletion of 90% (Table C-4).

	Years, assuming F=0	**Years, assuming F=0.05M**
Recovery to 30% of $\hat{B}$		
Catch history 1	87 (46)	111 (53)
Catch history 2	111 (46)	156 (52)
Recovery to 40% of $\hat{B}$		
Catch history 1	112 (59)	146 (69)
Catch history 2	144 (58)	208 (67)
Recovery to 50% of $\hat{B}$		
Catch history 1	135 (70)	182 (83)
Catch history 2	174 (69)	265 (82)
Recovery to 99% of $\hat{B}$		
Catch history 1	411 (196)	Never (Never)
Catch history 2	500+ (195)	Never (Never)

SENSITIVITY ANALYSIS

The production model's sensitivity to the fixed parameter M, the natural mortality rate, was evaluated for each of the two catch histories. Results generated by either decreasing or increasing M by 20%, i.e. to 0.0544 and 0.0816, are summarized in Table C - 12. The results do not differ significantly from the results obtained using M=0.068 (the default fixed value) when no fishing mortality past 2007 is allowed. When F=0.05M from 2007 and on the results tend to be slightly better, in terms of short recovery times, when M is decreased and conversely when M is increased. This is exacerbated especially when considering the 50% and 99% $\hat{N}$ and $\hat{B}$ reference points, i.e., on a longer time scale. In conclusion the model is not very sensitive to the fixed natural mortality rate M when no fishing mortality is experienced by the basking shark population after 2007. If the true natural mortality rate is lower than 0.068 this model could be considered conservative, however, if the true natural mortality rate is higher we may be underestimating recovery times.

Table C - 12. Sensitivity analyses for fixed parameter M in the production model. Where two values are listed, the first assumes $F_{future}=0$, and the second that $F_{future}=0.05M$.

Parameter	***M* - 20%**	***M* + 20%**
Change in $\hat{N}$		
Catch history 1	-2 sharks	+7 sharks
Catch history 2	-3 sharks	+1 shark
Change in N_{2007}		
Catch history 1	+3 sharks	+4 sharks
Catch history 2	-5 sharks	+4 sharks
Change in time to recover to 1000 breeding pairs, assuming 40% mature		
Catch history 1	Identical	Identical
Catch history 2	Identical	Identical
Change in time to recover to $\hat{N}_{30\%}$		
Catch history 1	Identical, -2 years	Identical, +1 year
Catch history 2	Identical, -1 year	-1 year, +1 year
Change in time to recover to $\hat{N}_{40\%}$		
Catch history 1	Identical, -3 years	Identical, +1 year
Catch history 2	+1 year, -2 years	Identical, +1 year
Change in time to recover to $\hat{N}_{50\%}$		
Catch history 1	Identical, -3 years	Identical, +3 years
Catch history 2	+1 year, -2 years	Identical, +3 years
Change in time to recover to 99% of $\hat{N}$		
Catch history 1	Identical, Identical	Identical, Identical
Catch history 2	+1 year, Identical	Identical, Identical
Change in time to $\hat{B}_{30\%}$		
Catch history 1	Identical, -2 years	Identical, +2 years
Catch history 2	Identical, +1 year	-1 year, +2 years
Change in time to $\hat{B}_{40\%}$		
Catch history 1	-1 year, -3 years	-1 year, +2 years
Catch history 2	Identical, -1 year	Identical, +3 years
Change in time to $\hat{B}_{50\%}$		
Catch history 1	-1 year, +4 years	Identical, +4 years
Catch history 2	Identical, -3 years	Identical, +4 years
Change in time to 99% of $\hat{B}$		
Catch history 1	Identical, Identical	Identical, Identical
Catch history 2	+1 year, Identical	Identical, Identical

SENSITIVITY TO ALTERNATIVE DEPLETION ASSUMPTIONS

In order to examine the sensitivity of the model to alternative depletion assumptions for the 1920 to 2007 period, we investigated the effect of increasing the assumed depletion from 90% to 95 % (case 1), and decreasing the assumed depletion from 90% to 85% (case 2).

Case 1: Assume 95% depleted

If we assume greater depletion between 1920 and 2007, that is, 95% rather than 90%, the unfished population size $\hat{N}$ decreases slightly (by <1%) for both catch histories when we calculate the likelihood of the scenarios that are resampled (Table C-13). For catch histories 1 and 2, the current population estimates decrease by 34% and 30% respectively (Table C-13). This means that when F=0, the recovery time to the four target biomass reference points increases by approximately 12 years, while when F=0.05M, recovery time increases by 14 years (Table C-14).

Table C-13. Posterior distribution means, 95% confidence intervals (in parentheses) for the unfished population size, $\hat{N}$ for catch histories 1 (minimum hypothesis) and 2 (maximum hypothesis) under the assumption of 95% depletion from 1920 - 2007. The difference relative to the original depletion of 90% (Table C-1) is given in square brackets.

	Catch history 1	**Catch history 2**
$\hat{N}$	2,952 (2,738 – 3,150) [-18]	4,794 (4,454 – 5,086) [-28]
N_{2007}	212 (14 – 552) [-109]	373 (20 – 883) [-162]

Table C - 14 . Biomass reference points. The table shows the number of years it takes for the population to recover to 30%, 40% and 99% of the original or unfished biomass $\hat{B}$ under the assumption of 95% depletion from 1920 -2007. The values in parentheses are the "95% confidence intervals" generated by starting the 2007 population from its associated 95% confidence interval. The difference relative to the original depletion of 90% (Table C-4) is given in square brackets.

	Years, assuming *F*=0	**Years, assuming *F*=0.05*M***
Recovery to 30% of $\hat{B}$		
Catch history 1	59 (27 – 151) [+13]	68 (31 – 181) [+15]
Catch history 2	57 (28 – 156) [+11]	65 (31 – 187) [+13]
Recovery to 40% of $\hat{B}$		
Catch history 1	72 (38 – 165) [+13]	83 (44 - 200) [+14]
Catch history 2	69 (39 – 169) [+11]	81 (44 – 206) [+14]
Recovery to 50% of $\hat{B}$		
Catch history 1	83 (48 – 177) [+13]	98 (57 - 219) [+15]
Catch history 2	80 (49 – 181) [+11]	96 (57 – 225) [+14]
Recovery to 99% of $\hat{B}$		
Catch history 1	209 (162 - 317) [+13]	Never [Never]
Catch history 2	207 (162 - 322) [+12]	Never [Never]

Case 2: Assume 85% depleted

If we assume less depletion between 1920 and 2007, that is, 85% rather than 90%, the unfished population size $\hat{N}$ increases when we calculate the likelihood of the scenarios that are resampled by about 20-35 sharks, an increase of < 1% for catch history 1 and 2 (Table C-15). For both catch histories, the current population increases, by 48% and 39% respectively (Table C-15). This means that when F=0, the recovery time to the four target biomass reference points decreases by approximately 12 years, while when F=0.05M, recovery time decreases by approximately 13 years (Table C-16).

Table C-15. Posterior distribution means, 95% confidence intervals (in parentheses) for the unfished population size, $\hat{N}$ for catch histories 1 (minimum hypothesis) and 2 (maximum hypothesis) under the assumption of 85% depletion from 1920 - 2007. The difference relative to the original depletion of 90% (Table C-1) is given in square brackets.

	Catch history 1	Catch history 2
$\hat{N}$	2,992 (2,738 – 3,203) [+22]	4,857 (4,495 – 5,174) [+35]
N_{2007}	475 (113 – 799) [+154]	744 (182 – 1,312) [+209]

Table C - 16. Biomass reference points. The table shows the number of years it takes for the population to recover to 30%, 40% and 99% of the original or unfished biomass $\hat{B}$ under the assumption of 85% depletion from 1920 - 2007. The values in parentheses are the "95% confidence intervals" generated by starting the 2007 population from its associated 95% confidence interval. The difference relative to the original depletion of 90% (Table C-4) is given in square brackets.

	Years, assuming *F*=0	**Years, assuming *F*=0.05*M***
Recovery to 30% of $\hat{B}$		
Catch history 1	34 (16 – 84) [-12]	39 (18 – 98) [-14]
Catch history 2	35 (15 – 84) [-11]	40 (17 – 99) [-12]
Recovery to 40% of $\hat{B}$		
Catch history 1	46 (27 – 97) [-13]	54 (31 - 116) [-15]
Catch history 2	47 (26 – 98) [-11]	55 (30 – 117) [-12]
Recovery to 50% of $\hat{B}$		
Catch history 1	57 (37 – 110) [-13]	68 (43 - 133) [-15]
Catch history 2	58 (36 – 110) [-11]	70 (43 – 134) [-12]
Recovery to 99% of $\hat{B}$		
Catch history 1	184 (150 - 250) [-12]	Never [Never]
Catch history 2	185 (149 - 250) [-10]	Never [Never]

CONCLUSION

Given the assumption that the Pacific population of basking sharks has declined by 90% from 1920 to 2007, the catch scenarios mentioned above have had a drastic effect on these large, slow-growing sharks. We estimate that it will take approximately 200 years for the population numbers of basking sharks to return to their unexploited state if human induced mortality is zero (i.e. F=0). We estimate that these fish will never return to their unexploited state at a low level of human induced mortality (i.e. F=0.05M). If these animals are completely protected against human induced harm, it could still take centuries for the population to recover to 1000 breeding pairs. Recovery to 30% of unexploited biomass $\hat{B}$ (i.e. the threshold above which a species is considered to be no longer Endangered but is considered to be threatened) could happen within 45 years if complete protection is afforded. However, even small levels of mortality would push this recovery target a further 10 years into the future. If human induced mortality is allowed to approach 0.5*M*, the basking shark populations could face extinction within 30 years.

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